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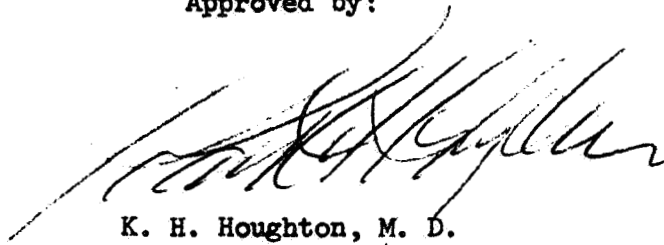
COST ANALYSIS OF WATER RECOVERY SYSTEMS

Contract No. NAS8-28377

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Section 1

INTRODUCTION AND SUMMARY

1.0 INTRODUCTION

A methodology has been developed to predict the relevant contributions of the more intangible cost elements encountered in the development of flight-qualified hardware based on an extrapolation of past hardware development experience. Major items of costs within life support subsystems have been identified and related to physical and/or performance criteria. Cost and performance data from Gemini, Skylab, and other aerospace and biotechnology programs were analyzed to identify major cost elements required to establish cost estimating relationships for advanced life support subsystems. The results of the study are expected to assist NASA in long-range planning and allocation of resources in a cost effective manner in support of earth orbital programs. This report deals with the cost analysis of the five leading water reclamation systems, namely 1) RITE waste management-water system; 2) reverse osmosis system; 3) multifiltration system; 4) vapor compression system; and 5) closed air evaporation system with electrolytic pretreatment.

2.0 APPROACH

The five leading water recovery systems have been quantitatively evaluated. System characteristics, including process flows, performance and physical characteristics were also analyzed. Additionally, the status of development of each of the systems considered and the required advance technology efforts required to bring conceptual and/or pre-prototype hardware to an operational prototype status were defined. Intimate knowledge of the operations, development status, and capabilities of the systems to meet space mission requirements were found to be essential in establishing the cost estimating relationships for advanced life support systems.

The following is a summary of the technical approach used. Included are the cost estimating techniques, the development of cost estimating relationships and the development of water systems cost estimates.

2.1 COST ESTIMATING TECHNIQUES

The water recovery systems cost estimating techniques were developed by 1) identifying the physical and performance characteristics of each of the system components; 2) establishing or utilizing existing cost estimating relationships (CER's) for each of the components considered; and 3) the summation of equations for respective system components to establish the total system cost estimation. The U.S. Bureau of Standards Consumer Price Index was used to account for inflation and economic escalation.

2.2 DEVELOPMENT OF COST ESTIMATING RELATIONSHIPS

The methodology used in the development of CER's is as follows:

1. The components were analyzed to determine which physical or performance characteristics might prove useful as predictive variables.
2. Costs were arrayed graphically against the candidate variables either singly or grouped. The most promising of these arrays were selected on the basis of a subjective analysis which considers the appropriateness of the variables, the form and slope of the curves, and the relative aspects of the component costs.

2.3 WATER RECOVERY SYSTEM COST ESTIMATES

A system schematic and a component identification list were prepared for each of the five water recovery systems. System and process descriptions, including system performance and characteristics, were also given. The physical and performance parameters were identified for use in formulating the cost estimating relationships. Recurring CER's were then developed and computed for each of the system subassemblies and summed up to obtain the integrated system recurring cost estimates. The system's non-recurring CER's were computed on an integrated system basis. The major influencing parameter for the non-recurring CER's was found to be the number of component types in the system.

Section 2

COST ESTIMATING TECHNIQUES

The methodology used in establishing cost estimating techniques for life support systems is based on 1) the identification of the physical and performance characteristics of each of the system components, 2) establishing or utilizing existing cost estimating relationships (CER's) for each of the components considered, and 3) the summation of equations for respective system components to establish the total system cost estimation. CER's developed in contract NAS9-9018 were used, with appropriate modifications, to estimate the cost of the components considered. For example, a gaseous storage tank CER was used for the CO₂ accumulator and the LiOH canister CER was used for the silica gel, molecular sieve, and regenerable solid desiccant canisters. The costs of small components such as manual and sequence valves were made on a weight basis. An assembly factor for integrating the components was also used.

Definition of the cost element structure and the application of the CER's are given in the following paragraphs.

COST ELEMENT STRUCTURE:

The cost element structure provides visibility of the total project expenditures and permits identification of the significant project costs. Expenditures are divided into nonrecurring and recurring:

Nonrecurring - The nonrecurring expenditures for each life support subsystem are segregated into Prime Contractor and Major Subcontractor efforts. The Prime Contractor effort involves specification, coordination and integration of the system into the spacecraft. The Major Subcontractor effort is divided into Design and Development, AGE, Program Management and System Engineering, Test Operations and Hardware. The Design and Development costs are segregated into major subsystems.

Recurring - The recurring expenditures are divided into the Prime Contractor and Major Subcontractor costs. The Prime Contractor efforts involve primarily the incorporation of the life support systems into the spacecraft. The Major Subcontractor costs are broken into Sustaining Engineering, Tooling and System Production. The System Production expenditures are segregated into subsystems and these are in turn segregated into components.

Table I presents a typical breakdown of the life support system expenditures, as encountered in the Gemini Program, divided in the respective non-recurring and recurring items. The major nonrecurring costs are those related to Design, AGE, and Prime Contractor's specification and procurement efforts. The major recurring cost item is that of flight hardware production.

EFFECT OF INFLATION ON COST ESTIMATES:

A major inherent feature of the methodology which is highly critical to the accuracy of the results obtained pertains to inflation and economic escalation. Since computed CER's are based on specific year dollars, they must be inflated to the proper year in order to obtain realistic future program values. Due to the lack of a specific aerospace price index, the yearly dollar value adopted in this report was considered to correspond to the Consumer Price Index. Figure 1 shows the Consumer Price Index based on data published by the U.S. Bureau of Statistics.

TABLE I - REPRESENTATIVE LIFE SUPPORT SYSTEM EXPENDITURE BREAKDOWN

NON-RECURRING	%	RECURRING	%
Design	16.68	Flight Hardware Production	54.56
Subcontractor General & Administrative	8.62	Subcontractor G&A	9.22
Subcontractor Fee	3.62	Subcontractor Fee	3.88
Program Management	1.24	program Management	1.36
System Engineering	5.25	Sustaining Engineering	1.96
Development Test	3.44		
Qualification Test	2.54		
Reliability Test	4.09		
AGE	18.45		
Tooling	3.87	Sustaining Tooling	1.69
Non-accountable Test Hardware	1.67		
Specifications, Vendor Coordination and Procurement Expenses	13.62	Specifications, Vendor Coordination and Procurement Expenses	15.49
System Integration	8.36	System Integration	7.15
Prime's Testing	8.17	Minor Subcontracts	4.69
Minor Subcontracts	0.38		
TOTAL	100%		100%

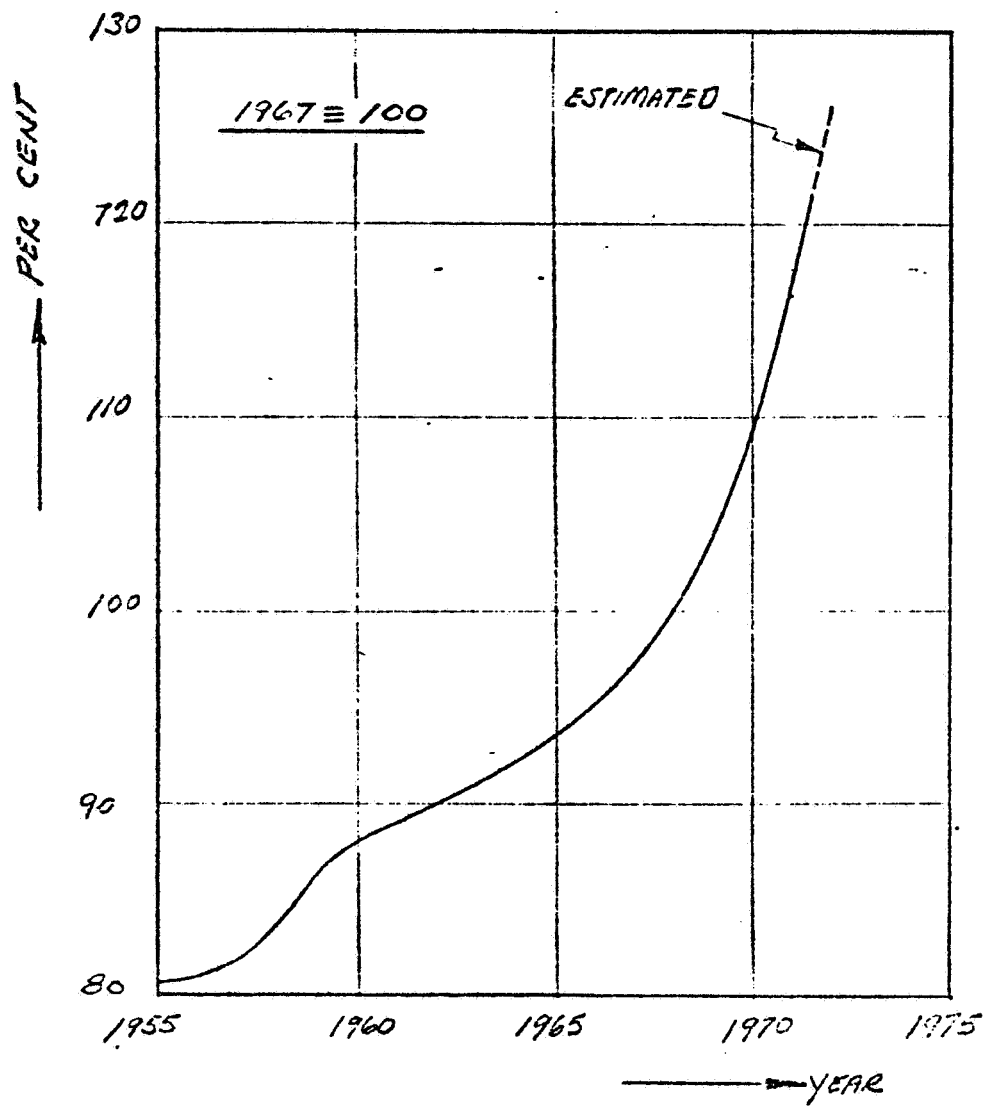


FIGURE I - Consumer Price Index
(Source: U. S. Bureau of Labor Statistics)

Section 3
COST ESTIMATES OF WATER RECOVERY SYSTEMS

3.1 RITE WASTE MANAGEMENT - WATER SYSTEM (WM-WS):

Process Description:

The RITE system is the most advanced concept water-waste management system under development. It has the capability of recovering water from all spacecraft waste materials including feces and can also shred and process trash. It goes one step further than other systems by automatically pumping the brine-sludge residue from the water recovery unit to an incinerator that reduces the solid wastes to an innocuous ash. All of the process heat used in the system is produced from low penalty isotopic sources. A simplified schematic of the system is shown in Figure 2.

The RITE system operation is described as follows. The integrated waste management and water recovery system (RITE) processes solid waste to an end product of sterile ash in addition to recovering and purifying water for reuse. Radioisotope thermal energy (RITE) is used as the heat source.

Trash, feces, wash water and urine solids are concentrated in the evaporator and moved by a solids pump to the incinerator. The incinerator vacuum dries and thermally decomposes the solids at a temperature of 1200°F. This reduces the weight of the solids approximately 90-95 percent. After thermal decomposition, a small flow of oxygen to the incinerator is used to reduce the solids weight and volume to approximately 1 percent of the original. This small amount of sterile ash may be stored or jetisoned.

The effluent in the evaporator is driven centrifugally by an impeller to provide a gravitational field that permits nucleate boiling. The evaporator is operated at 120°F or less, and at approximately 1.7 psia. This low boiling temperature is maintained to minimize generation of gaseous products by thermal decomposition.

The steam from the evaporator passes through pyrolysis units that are equipped with counter-flow heat exchangers and catalytic beds. The high temperature RITE heater superheats the steam to 1200°F. This high temperature sterilizes the steam and a small flow of oxygen that is metered into the steam is used in catalytic oxidation of entrained gaseous impurities.

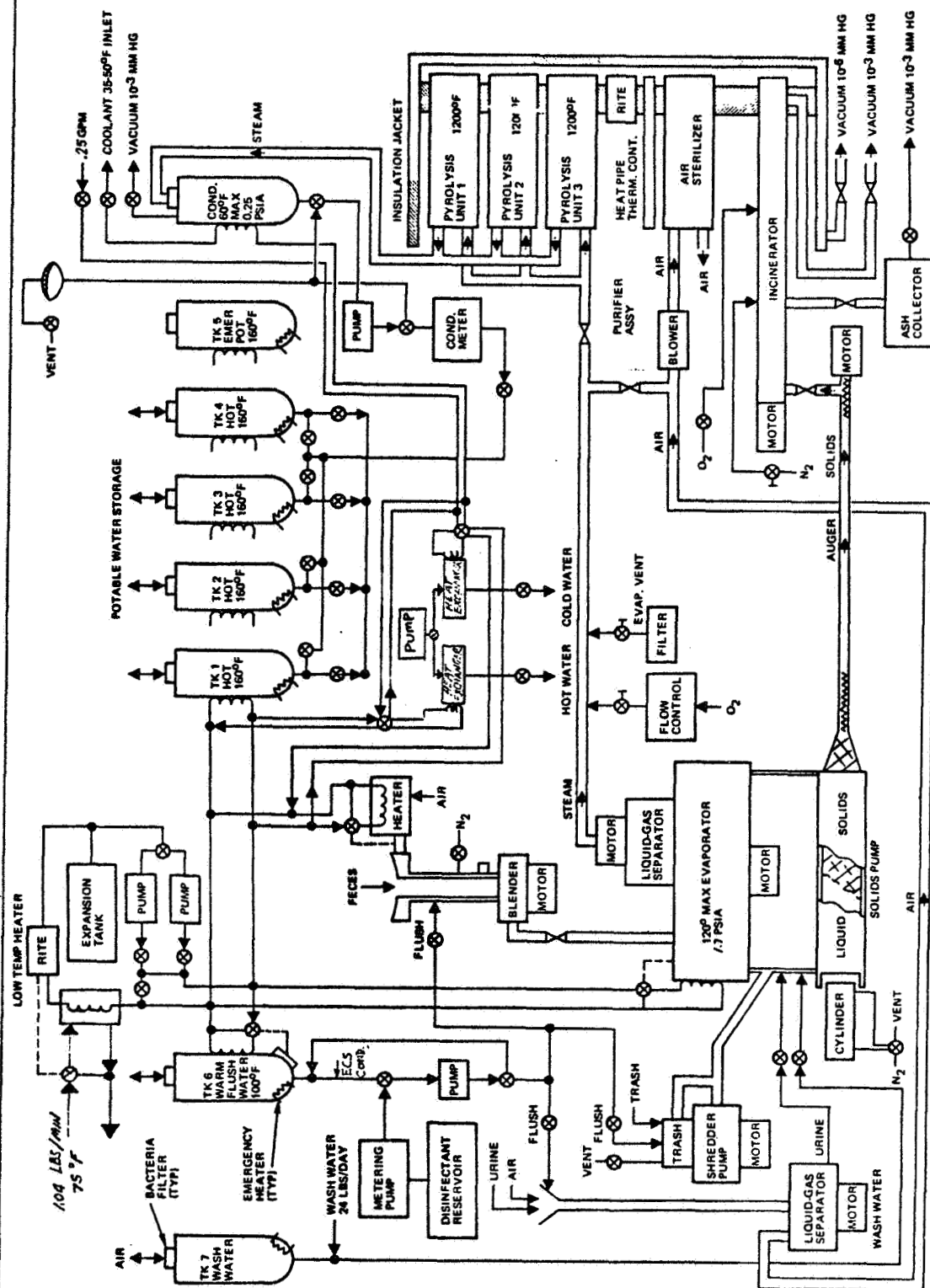


Figure 2 Integrated Waste Management System Using Radioisotopes for Thermal Energy

The steam passes from the pyrolysis units to the condenser. The steam is condensed at about 60°F and 0.26 psia in the condenser. This pressure is less than evaporator pressure and forces the steam flow through the system. Gases in the steam flow (that are not eliminated in the pyrolysis units) are vented to space vacuum from the condenser.

In the RITE configuration, the purified water is pumped out of the condenser periodically. It passes through conductivity and pH sensors to a set of potable water storage tanks. The tanks are filled in rotation, and tested for chemical and microbiological purity prior to use.

The low temperature RITE heater provides heat for the evaporator and the water storage tanks. The tanks are heated (160°F) to prevent microbial growth. The flush water tank is heated to 100°F and disinfectant is automatically added to this water to maintain sterility.

The system is automatically controlled to function in a fail safe manner. Alarms warn of any failures that have occurred. If any component in the system ceases to function, components that supply effluent to it are automatically shut down.

Overheat of the RITE heaters is prevented by discharging surplus heat to compartment air. The high temperature RITE heater discharges surplus heat through a heat pipe to the compartment air. The low temperature RITE heater is protected from overheat by a fan and heat exchanger; excessive heater temperature activates the fan and causes a portion of the heater output to be transferred to the compartment air.

The water storage and distribution system shown in Figure 2 includes four storage tanks to be rotated in a 48-hour sequence in which the status at any particular time is: one tank being filled, one tank being chemically and microbiologically checked, one tank certified potable awaiting use, and one tank being used. Flexible quick-disconnect lines are used to effect the proper sequencing and achieve isolation after the fill cycle thus obviating any chance of inadvertent contamination as a result of back-flow or seepage

such as might occur in a hard-plumbed system. The circulation pump can provide a continuous flow of hot water from the tank in use to the use point and return. This prevents bacterial growth during nonusage, in an otherwise stagnant line.

System Performance and Characteristics:

The physical, performance and chemical characteristics of the RITE waste management-water system are given as follows:

Process Water Input	= 57.2 lbs/day
Process Water Output	= 54.0 lbs/day
RITE System Recovery Efficiency	= 94.5%
Water Loop Mass and Heat Balances:	
1. Flush Water Tank Flow Rate	= 20 lbs/day
2. Flush Water Input Temperature	= 70°F
3. Flush Water Output Temperature	= 100°F
4. Flush Water Tank Heat Input	= 47.1 Btu/hr
5. Flush Water Tank Heat Loss	= 30 Btu/hr
6. Evaporator Inputs, in lbs/day:	
Flush Water	= 20.0
Urine Solids	= 0.8
Urine Liquid	= 13.2
Wash Water	= 24.0
Feces	= 1.2
Trash	= 1.2
7. Evaporator Outputs, in lbs/day	
Water	= 56.0
Feces	= 1.2
Trash	= 1.2
Waste Water	= 1.2
Urine Solids	= 0.8
8. Evaporator Heat Input	= 2615 Btu/hr
9. Evaporator Heat Loss	= 145 Btu/hr
10. Heater Flow Rate	= 56 lbs/day

11. Heater Inlet Temperature = 103°F
12. Heater Outlet Temperature = 165°F
13. Heater Heat Input = 64 Btu/hr
14. Pyrolysis Chamber Heat Input = 206 Btu/hr
15. Pyrolysis Chamber Outlet Temperature = 370°F
16. Condenser Inlet Temperature = 100°F
17. Condenser Outlet Temperature = 60°F
18. Condenser Heat Rejection = 2385 Btu/hr
19. Condenser Water Loss = 2.0 lbs/day
20. Storage Tank Flow Rate = 54.0 lbs/day
21. Storage Tank Outlet Temperature = 145°F
22. Heat Input to Storage Tank = 202 Btu/hr
23. Incinerator Inputs, in lbs/day:
 - Feces = 1.2
 - Trash = 1.2
 - Water = 1.2
 - Urine Solids = 0.8
24. Heat Input to Incinerator = 127 Btu/hr

Low Temperature Heating Loop:

1. Isotope Heat Output = 5120 Btu/hr
2. Heating Fluid Inlet Temperature = 158°F
3. Total Heating Fluid Total Flow Rate = 426 lbs/hr
4. Heating Fluid Heat Flow to Components:
 - Flush Tank = 47.1 Btu/hr
 - Evaporator = 2615 Btu/hr
 - Potable Water Tank, each of 4 tanks = 190 Btu/hr
 - Emergency Water Tank = 135 Btu/hr
 - Line Losses = 812 Btu/hr
5. Heating Fluid Flow Rates to Components:
 - Flush Tank = 5.6 lbs/hr
 - Evaporator = 313 lbs/hr
 - Potable Water Tanks, each of 4 tanks = 22.8 lbs/hr
 - Emergency Tank = 16.2 lbs/hr

Coolant Loop

1. Coolant Inlet Temperature	= 30°F
2. Coolant Total Flow Rate	= 158 lbs/hr
3. Coolant Flow Rate to Condenser	= 142 lbs/hr
4. Coolant Flow Rate to Water Cooler	= 16 lbs/hr
5. Condenser Heat Load	= 2385 Btu/hr
6. Coolant Loop Outlet Temperature	= 49.6°F

RITE System Mass and Heat Balances:

1. Urine Input to Urinal	= 14.0 lbs/day
2. Number of Micturations Per Day	= 24
3. Air Flow to Urinal During Urination	= 20 cfm
4. Trash Input, Solids	= 1.2 lbs/day
5. Number of Trash Deposits per Day	= 4
6. Amount of Water In Trash	= 2.4 lbs/day
7. Airflow to Blender During Defacation	= 40 cfm
8. Defacation Time, Nominal	= 10 minutes
9. Coolant Flow Rate to Condenser	= 0.25 gpm
10. Coolant Inlet Temperature to Condenser	= 30°F
11. Coolant Outlet Temperature from Condenser	= 45°F
12. Air Sterilizer Operating Temperature	= 1250°F
13. Isotope Heat Input to Sterilizer	= 44 watts
14. Pyrolysis Chamber Operating Temperature	= 1250°F
15. Isotope Heat Input to Pyrolysis Chamber	= 65 watts
16. Isotope Heat Input to Incinerator	= 72 watts
17. Heat Loss from Heat Block	= 219 watts
18. Heat Loss from Heat Pipe	= 60 watts
19. Total Heat Supplied by Isotope to Heat Block	= 460 watts

A complete listing of the components of the RITE System is shown in Table II.

TABLE II
RITE SYSTEM COMPONENTS LIST

COMPONENT	QUANTITY	SPARES	UNIT WEIGHT (LBS)
Valve, Shut-off, Manual	30	10	1.0
Valve, Solenoid	5	3	2.0
Valve, Solenoid, Vacuum	4	3	2.5
Valve, 3-way, Electrical	9	4	1.5
Valve, 3-way, Manual	1	1	1.0
Valve, 4-way, Electrical	2	1	2.0
Tank, Water Storage	7	7	60.0
Pump, Liquid	5	3	3.5
Pump, Metering	1	1	2.0
Pump, Solids, including Trash Compactor and Auger	1	1	10.0
Trash Collector and Shredder	1	1	8.0
Separator, Liquid-Gas	2	2	3.0
Blender, Feces	1	1	6.0
Filter	1	1	3.0
Blower	1	1	2.0
Isotope Heater Assembly, Heat Block	1	0	8.0
Isotope Heater Assembly, Heating Loop	1	0	10.0
Evaporator, Centrifugal	1	1	6.0
Heat Exchanger, Liquid-Liquid	3	2	10.0
Heat Exchanger, Liquid-Air	1	1	8.0
Condenser	1	1	6.0
Urinal	1	1	0.6
Flow Control, Oxygen	1	1	2.0
Pyrolysis Chamber	3	1	15.0
Heat Pipe	1	1	3.0
Air Sterilizer	1	1	14.0
Incinerator	1	0	30.0
Motor	7	7	2.0
Commode	1	0	5.0

TABLE II
RITE SYSTEM COMPONENTS LIST (CONT)

COMPONENT	QUANTITY	SPARES	UNIT WEIGHT (LBS)
Conductivity Meter	1	1	0.2
Quantity Sensor	7	7	1.0
Ash Collector	1	0	20.0
Heat Block, including Insulation Jacket	1	0	45.0
Temperature Sensor	49	20	0.1
Pressure Sensors	2	2	1.5
Reservoir, Disinfectant	1		
Controller	1	1	15.0
Measurement Switching Unit	1	0	15.6
Measurement Unit	1	0	14.4

Cost Estimating Relationships:

The components utilized in the RITE Waste Management-Water System have been grouped into twenty-two groups, designated as I through XXII, as shown in the system schematic, Figure 2. The recurring and non-recurring CER's presented in the following paragraphs are based on estimated January, 1972 dollars. The Consumer Price Index was used to adjust CER's developed and based on prior years' dollar values.

Recurring CER's:

1. ECS Condensate Pump and Disinfectant Loop

The CER for the ECS condensate pump and the disinfectant loop, which comprises a pump and a disinfectant reservoir, is given by the following relation:

$$\begin{aligned} &\text{Condensate Pump and Condensate Loop Fabrication Cost C} \\ &= 91 P_{W_I}^{0.942} + P_{W_2}^{0.942} + 1918V^{0.267} + 670 W_{OC} \text{ dollars} \end{aligned}$$

where,

P_{W_1} = Condensate pump power input = 500 watts,

P_{W_2} = Metering pump power input = 20 watts,

V = Disinfectant Reservoir Volume = 0.4 ft^3 , and

W_{OC} = Other components weight = 2 lbs.

Substituting the values of the variables in the above CER yields the following:

$$\begin{aligned} C &= 91 \times 500^{0.942} + 20^{0.942} + 1,918 \times (0.4)^{0.267} + 670 \times 2 \\ &= 91 \times 350 + 16.8 + 1918 \times 0.784 + 1340 \\ &= 33,379 + 1503.7 + 1340 = 36,223 \text{ dollars} \end{aligned}$$

2. Urinal and Gas Separator:

The urinal and gas-liquid separator CER is given by the following relation:

Urinal and Separator Assembly Fabrication Cost C

$$= 91 P_W^{0.942} + 670(W_u + W_{OC}) \text{ dollars}$$

where,

P_W = Power input to separator = 200 watts,

W_u = Urinal weight = 0.6 lbs., and

W_{OC} = Associated components weight = 1.0 lb.

Substituting the values of variables in the above CER yields the following:

$$\begin{aligned} C &= 91 \times (200)^{0.947} + 670 \times 1.6 \\ &= 91 \times 148 + 670 \times 1.6 = 14,540 \text{ dollars} \end{aligned}$$

3. Trash Shredder/Pump:

The trash shredder/pump assembly CER is given by the following relation:

Urinal and Separator Assembly Fabrication Cost C

$$= 91 P_W^{0.942} + 670 W_{OC} \text{ dollars}$$

where,

P_W = Power input to trash shredder/pump = 975 watts, and

W_{OC} = Associated components weight = 3.0 lbs.

Substituting the vlaues of variables in the above CER yields the following:

$$\begin{aligned} C &= 91 \times (975)^{0.947} + 670 \times 3.0 \\ &= 91 \times 660 + 670 \times 3.0 = 62,070 \text{ dollars} \end{aligned}$$

4. Potable and Waste Water Tanks:

The CER for the potable and waste water tanks is given as follows:

$$\text{Tanks Fabrication Cost } C = 1,918 V^{0.267} Q^{0.89} + 2959 W_{OC} \text{ dollars}$$

where,

V = Volume of tanks = 1.0 ft^3 ,

Q = Number of tanks = 7, and

W_{OC} = Weight of other components = 16.5 lbs.

Substituting the above values in the tanks' fabrication cost equation results in the following:

$$C = 1918 \times 1 \times 5.7 + 2959 \times 16.5 = 59,756 \text{ dollars}$$

5. Low Temperature Loop Heat Exchanger:

The CER for the low temperature loop, liquid-to-liquid heat exchanger is given by the following:

Heat Exchanger Fabrication Cost C

$$= 159 W^{0.267} N_P^{1.905} + 2959 W_{OC} \text{ dollars}$$

where, W = heat exchanger weight = 10.0 lbs.,

N_P = number of ports per heat exchanger = 4,

W_{OC} = weight of other components = 1.0 lbs.

Substituting the values of the variable in the CER yields:

$$C = 159 \times 1.85 \times 14.05 + 2959 \times 1.0 = 4136 \text{ dollars}$$

6. Heating Loop Isotope Heater Assembly:

The CER for the heating loop isotope assembly deals with the tank type heat exchanger and heat block, around which the heating fluid is circulated. The cost of the radioisotope heating elements is not included in the estimate. The CER for the heater assembly is given by the following relation:

Heating Loop Isotope Heater Assembly Fabrication Cost C

$$= 1918 V^{0.267} + 159 W^{0.267} N_P^{1.905} + 2959 W_{OC} \text{ dollars}$$

where,

V = Tank Volume = 3.35 ft³,

W = Heat Exchanger Weight, comprising heat block = 20 lbs.,

N_P = Number of heat exchanger ports = 2, and

W_{OC} = Weight of associated components = 1.0 lb.

Substituting the values of the variables in the above CER yields the following:

$$\begin{aligned}
C &= 1918 \times (3.35)^{0.267} + 159 \times (20)^{0.267} \times 2^{1.905} + 2959 \times 1 \\
&= 1918 \times 1.373 + 159 \times 2.228 \times 3.72 + 2959 \\
&= 2633 + 1318 + 2959 = 6910 \text{ dollars}
\end{aligned}$$

7. Expansion Tank:

The CER used for the expansion tank is the same equation utilized for the water tanks and is given as follows:

Expansion Tank Fabrication Cost C

$$= 1918 V^{0.267} + 2959 W_{OC} \text{ dollars}$$

where,

V = Tank Volume = 1.0 ft^3 , and

W_{OC} = Weight of associated components = 1.0 lb.

Substituting the values of the variables in the above CER gives the following:

$$C = 1918 + 2959 = 4877 \text{ dollars}$$

8. Heating Loop Pumps:

The heating loop pumps CER is given by the following relation:

Pumps Fabrication Cost C

$$= 91 P_W^{0.942} Q^{0.89} + 670 W_{OC}$$

where,

P_W = Electrical power input to circulation pump = 92 watts,

Q = Number of transfer pumps = 2, and

W_{OC} = Weight of other components = 1.0 lb.

Substituting the values of the above variables in the pumps fabrication cost equation results in the following:

$$C = 91 \times 71 \times 1852 + 670 \times 1 = 12,636 \text{ dollars}$$

9. Feces Blender and Commode Seat:

The CER utilized for the feces blender and the commode seat is given by the following:

Feces Blender Assembly Fabrication Cost C

$$= 91 P_W^{0.942} + 3900 W_{OC} \text{ dollars}$$

where,

P_W = Blender power requirement = 370 watts, and

W_{OC} = Associated components weight = 9 lbs.

Substituting the values of variables in the above CER yields:

$$C = 91 \times 268 + 3900 \times 9 = 59,488 \text{ dollars}$$

10. Evaporator Assembly:

The evaporator assembly includes a liquid-gas separator, the rotating evaporator and associated valves. The CER for the evaporator assembly is given by the following:

Evaporator Assembly Fabrication Cost C

$$= 91 (P_{W_1}^{0.942} + P_{W_2}^{0.942}) + 159 W^{0.267} N_P^{1.905} + 3900 W_{OC} \text{ dollars}$$

where,

P_{W_1} = Power input to evaporator motor = 20 watts,

P_{W_2} = Power input to separator = 200 watts,

W = Evaporator weight = 6.0 lbs.,

N_P = Number of evaporator ports = 4, and

W_{OC} = Weight of associated components = 1.0 lb.

Substituting the values of variables in the above CER yields:

$$\begin{aligned} C &= 91 (20^{0.942} + 200^{0.942}) + 159 \times 6^{0.267} \times 14.05 + 3900 \\ &= 91 \times (16.8 + 148) + 159 \times 1.614 \times 14.05 + 3900 \\ &= 22,503 \text{ dollars} \end{aligned}$$

11. Air-Liquid Heat Exchanger:

The commode air-liquid heat exchanger CER is given by the following:

Heat Exchanger Fabrication Cost C

$$= 159 W^{0.267} N_P^{1.905} + 2959 W_{OC} \text{ dollars}$$

where,

W = heat exchanger weight = 8.0 lbs.,

N_P = Number of ports per heat exchanger = 4,

W_{OC} = Weight of other components = 1.5 lbs.

Substituting the values of the variable in the CER yields:

$$C = 159 \times 1.744 \times 14.05 + 2959 \times 1.5 = 8335 \text{ dollars}$$

12. Solids Pump:

The CER for the solids pump, including the compacting cylinder and the transport auger, has been based on similar hardware of comparable complexity and is given by the following:

Solids Pump Fabrication Cost C

$$= 2192 W + 670 W_{OC} \text{ dollars}$$

where,

W = Weight of solids pump = 10.0 lbs., and

W_{OC} = Weight of associated components = 1.0 lb.

Substituting the values of variables in the above CER yields:

$$C = 21920 + 670 = 22,590 \text{ dollars}$$

13. Potable Water Transfer Pump:

The potable water transfer pump CER is given by the following relation:

Pumps Fabrication Cost C

$$= 91 P_W^{0.942} + 670 W_{OC}$$

where,

P_W = Electrical power input to transfer pumps = 30 watts,

W_{OC} = Weight of other components = 3.0 lbs.

Substituting the values of the above variables in the pumps fabrication cost equation results in the following:

$$C = 91 \times (30)^{0.942} + 670 \times 3 = 4250 \text{ dollars}$$

14. Potable Water Heater and Cooler:

Both the water heater and cooler are identical size liquid-to-liquid heat exchangers. The CER for the potable water heater and cooler assembly is given as follows:

Water Heater and Cooler Fabrication Cost C

$$= 159 W^{-.267} N_P^{1.905} Q^{0.89} + 2959 W_{OC} \text{ dollars}$$

where, W = heat exchanger weight = 10.0 lbs.,

N_P = number of ports per heat exchanger = 4,

Q = number of heat exchangers used = 2, and

W_{OC} = weight of other components = 4 lbs.

Substituting the values of the variable in the CER yields:

$$C = 159 \times 1.85 \times 14.05 \times 1.855 + 2959 \times 4 = 18,046 \text{ dollars}$$

15. Pyrolysis Units Assembly:

The Pyrolysis Units Assembly is given by the following:

Pyrolysis Units Assembly Fabrication Cost C

$$= 159 W^{0.267} N_P^{1.905} Q^{0.89} + 3900 W_{OC} \text{ dollars}$$

where,

W = pyrolysis chamber weight = 15.0 lbs.

N_P = number of ports per pyrolysis chamber = 2,

Q = number of pyrolysis units = 3, and

W_{OC} = weight of associated components = 9.0 lbs.

Substituting the values of variables in the CER yields:

$$C = 159 \times 2.062 \times 3.72 \times 2.66 + 3900 \times 9 = 38,344 \text{ dollars}$$

16. Condensate Pump:

The CER for the condensate pump assembly is given by the following relation:

Condensate Pump and Condensate Loop Fabrication Cost C

$$= 91 P_W^{0.942} + 670 W_{OC} \text{ dollars}$$

where,

P_W = condensate pump power input = 500 watts,

W_{OC} = other components weight = 2.7 lbs.

Substituting the values of the variables in the above CER yields the following:

$$C = 91 \times 350 + 670 \times 2.7 = 33,659 \text{ dollars}$$

17. Condenser Assembly:

The condenser assembly includes a tank-type condenser and associated valves. The CER for the condenser assembly is given as follows:

Condenser Assembly Fabrication Cost C

$$= 80 W^{0.267} N_P^{1.905} + 960 V^{0.267} + 2959 W_{OC} \text{ dollars}$$

where,

W = Condenser weight = 6.0 lbs.,

V = Condenser volume = 0.6 ft^3

N_P = Number of ports per condenser = 4, and

W_{OC} = Weight of other components = 6.5 lbs.

Substituting the values of variables in the CER yields:

$$\begin{aligned} C &= 80 \times 1.614 \times 14.05 + 960 \times (0.6)^{0.267} + 2959 \times 6.5 \\ &= 1814.1 + 946.7 + 19,233.5 = 21,994 \text{ dollars} \end{aligned}$$

18. Heat Pipe:

The heat pipe assembly cost is also based on a weight basis and is estimated by comparison to similar hardware. The CER for the heat pipe assembly is given as follows:

Heat Pipe Assembly Fabrication Cost C

$$= 2000 W_H \text{ dollars}$$

where, W_H = heat pipe weight = 3.0 lbs.

then,

$$C = 2000 \times 3 = 6000 \text{ dollars.}$$

19. Air Sterilizer:

The air sterilizer assembly CER is given by the following:

Air Sterilizer Assembly Fabrication Cost C

$$= 159 W^{0.267} N_P^{1.905} + 3000 W_{OC} \text{ dollars}$$

where,

W = Air Sterilizer weight = 14.0 lbs.

N_P = Number of ports per sterilizer chamber = 2,

Q = Number of pyrolysis units = 3, and

W_{OC} = Weight of associated components = 1.0 lb.

Substituting the values of variables in the CER yields:

$$C = 159 \times 2.023 \times 3.72 + 3000 \times 1 = 4197 \text{ dollars}$$

20. Air Blower:

The influencing parameter in the air blower fabrication is the electrical power input to the unit. The CER is given as follows:

Air Blower Fabrication Cost C

$$= 38.2 P^{0.942} + 2192 W_{OC} \text{ dollars}$$

where,

P = electrical power input to the compressor 160 watts, and

W_{OC} = weight of other components = 2.0 lbs.

Substituting these values in the above equation yields the following:

$$C = 38.223 \times 120 + 2192 \times 2.0 = 8970 \text{ dollars}$$

21. Incinerator:

The CER for the incinerator assembly, comprising the incinerator, ash collector and associated components, is given by the following:

Incinerator Fabrication Cost C

$$= 159 W^{0.267} N_P^{1.905} + 3900 W_{OC} \text{ dollars}$$

where,

W = incinerator weight = 20.0 lbs,

N_P = number of ports per pyrolysis chamber = 2,

W_{OC} = weight of associated components = 6.0 lbs.

Substituting the values of variables in the CER yields:

$$C = 159 \times 2.228 \times 3.72 \times 3900 \times 6 = 24,718 \text{ dollars}$$

22. Heat Block and Insulation Jacket:

The heat block and insulation jacket assembly cost is based on a weight basis and is estimated by comparison to similar hardware. The heat block and insulation jacket CER is given as follows:

Insulation Jacket Fabrication Cost C

$$= 600 (W_B + W_j) \text{ dollars}$$

where,

W_B = Heat block weight in pounds, and

W_j = Insulation jacket weight in pounds.

Substituting the weights of the heat block and insulation jacket in the above CER yields:

$$C = 600 \times 45 = 27,000 \text{ dollars.}$$

Integrated RITE System's Recurring CER:

The integration costs of components and assemblies into the RITE system are obtained by utilizing the system's recurring CER as defined in previous sections of this report. Applying the said CER, then:

$$\begin{aligned}
\text{First unit cost } C_F &= 1.833 \times 1.1 \times (36,223 + 14,540 + 62,070 + 59,756 \\
&\quad + 4,136 + 6,910 + 4,877 + 12,636 + 59,488 + 22,503 \\
&\quad + 8,335 + 22,590 + 4,250 + 18,046 + 38,344 + 33,659 \\
&\quad + 21,994 + 6,000 + 4,197 + 8,970 + 24,718 + 27,000) \\
&= 2.016 \times 501,242 = 1,010,634 \text{ dollars}
\end{aligned}$$

and assuming the production of two flight-type units, one for flight and the other for back-up, then the total hardware cost is given by:

$$\begin{aligned}
C_T &= 1,010,634 \times (2)^{1-0.1047} \\
&= 1,879,780 \text{ dollars}
\end{aligned}$$

Integrated RITE System's Non-Recurring CER's:

Non-recurring CER's have been developed for engineering design only. Other non-recurring cost estimates are based on the cost breakdown ratios utilized in the case of the molecular sieves system which have been based on actual cost data collected in NAS9-9018 study. The analysis of a number of cost influencing parameters indicated that engineering design CER is mainly a function of the number of component types (N) in each system and is given by the following relation.

$$\begin{aligned}
\text{System design cost } C & \\
&= 34,935N + 102,942 \text{ dollars}
\end{aligned}$$

The regenerable solid desiccant system comprises 39 component types as shown in Table II. Accordingly, system design cost $C = 1,362,465 + 102,942 = 1,465,407$ dollars.

Values of other non-recurring cost items are listed in Table III which also shows the breakdown of recurring cost items based on the production of two flight hardware units. All cost figures are in estimated January 1972 dollars.

TABLE III - RITE SYSTEM COST BREAKDOWN

Non-Recurring		Recurring	
System Engineering Design	1,465,407	Flight Hardware	1,025,608
Subcontractor General and Administrative	757,615	Subcontractor G&A	173,318
Subcontractor Fee	317,993	Subcontractor Fee	72,935
Program Management	109,906	Program Management	25,565
System Engineering	461,603	Sustaining Engineering	36,841
Development Test	301,874		
Qualification Test	222,742		
Reliability Test	359,025		
AGE	1,620,740		
Tooling	339,974	Sustaining Tooling	31,768
Non-accountable Test Hardware	146,541		
Specifications, Vendor Coordination and Procurement Expense	1,197,238	Specifications, Vendor Coordination and Procurement Expense	291,178
System Integration	734,169	System Integration	134,404
Prime's Testing	718,049		
Minor Subcontracts	33,704	Minor Subcontracts	88,161
Total	8,786,580		1,879,780

Total RITE System Cost = 8,786,580 + 1,879,780 = 10,666,360 dollars

3.2 REVERSE OSMOSIS SYSTEM:

System Description:

This system is used for providing a sanitary means of collecting waste wash water and processing it for reuse in showers, sinks, and wash machines. The waste water initially passes through an expendable 30 micron mesh filter screen to remove large suspended solids such as hair, skin and lint. Figure 3 is a schematic which shows the major system components. The waste water is stored in a 134 lbs holding tank. A 1-micron filter is located downstream of the holding tank and a high pressure pump is used to deliver the water to the reverse osmosis module. The pressure is controlled by a downstream constant flow pressure regulator which varies the cell operating pressure between 265 and 600 psi. The wash water processor module includes a reverse osmosis cell made of DuPont permasep material and accessory equipment required to concentrate wash water and obtain fresh water. Since the permeation rate of the permasep is proportional to operating temperature, the reverse osmosis cell membrane area is sized for the lowest operating temperature (65°F). Permeate water is transferred through a conductivity meter and a motor driven three-way valve. If the conductivity is more than a predetermined value, the valve transfers the water back into the waste feed line where it is then reprocessed. If the conductivity is below the acceptable value, the valve transfers the water to the Water Storage and Sterilization Subsystem through a bacteria/charcoal filter. The brine from the RO cell is transferred through a constant flow pressure regulator, a conductivity meter and a three-way electrical valve. If the conductivity is high, the brine is discharged but if the conductivity is within acceptable limits, it is transferred by a recirculation pump to the waste feed line for reprocessing.

The wash water circuit interfaces with the sanitary washing facilities and receives the waste water from them at temperatures that can range up to 160°F. Due to heat transfer, it is not expected that the water temperature will be above room ambient by the time it reaches the processing unit. The waste storage tank has a capacity for 222 lbs of water and can therefore store all the wash water for a normal day's activity. The time line requirement storage capability is based on providing water for 5 showers in 0.45 hours. The germicide used in the wash water will serve to maintain the bacteria in an inhibited state. The dissolved solids are not collected in this subsystem but are transferred in

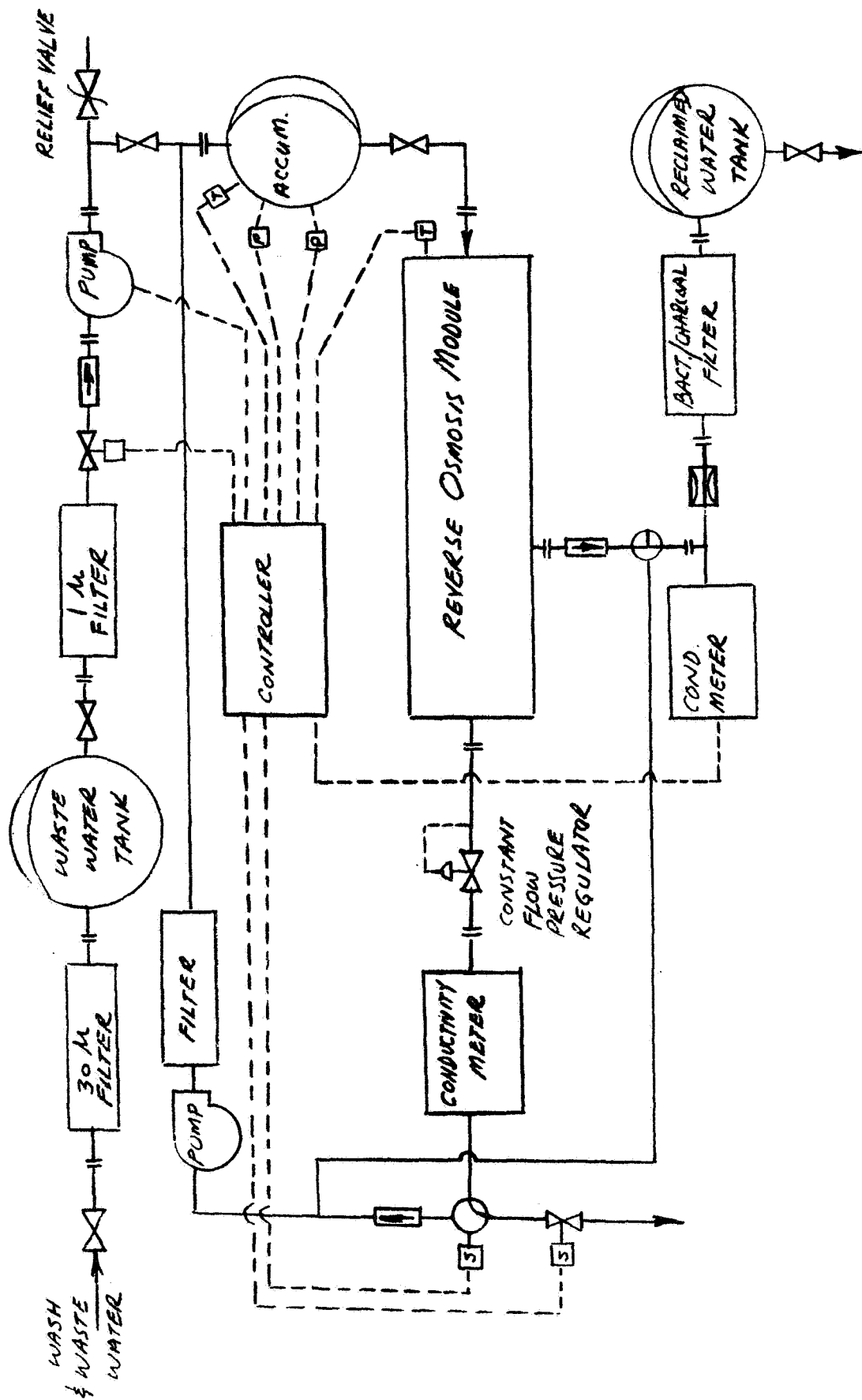


FIGURE 3 REVERSE OSMOSIS SYSTEM

concentrated brine to the urine water recovery system for further processing and/or disposal.

System Performance and Characteristics:

The physical, performance and interface characteristics of the reverse osmosis system are as follows:

Crew size	= 6 men
Wash water processing requirement	= 224 lbs/day
System process rate	= 0.056 gpm
Components design pressure	= 800 psig
Feed water temperature	= 165 \pm 10 °F
Feed water pressure	= 20 \pm 5 psig
Discharge water temperature	= 160 \pm 10 °F
Discharge water and brine pressures	= 0 to 30 psig
Reverse osmosis system dimensions	= 27" x 12" x 26"
Reverse osmosis system weight	= 200 lbs.

Table IV
REVERSE OSMOSIS SYSTEM
COMPONENT WEIGHTS

COMPONENT	QUANTITY	SPARES	UNIT WEIGHT (LBS)
Valve, check liquid	3	0	0.69
Valve, shutoff, electrical	3	3	1.30
Valve, shutoff, manual	6	0	0.80
Valve, 3-way electrical, manual override	1	0	1.44
Valve, flow regulator	1	2	1.40
Disconnect, with cap	3	0	0.80
Valve, relief, 40 psig, R.O.	1	1	1.40
Filter, debris, wash H ₂ O	1	1	5.00

Table IV
REVERSE OSMOSIS SYSTEM
COMPONENT WEIGHTS
(Continued)

COMPONENT	QUANTITY	SPARES	UNIT WEIGHT (LBS)
Filter, R.O.	1	2	5.00
Filter, H ₂ O	2	0	3.00
Filter, activated charcoal/bacteria	1	0	9.00
Pump, circulating	2	2	3.50
Pump, R.O., high pressure with relief	1	2	20.00
Storage tank, processed water	1	0	25.00
Regulator, tank pressure	3	0	1.5
Controller, R. O.	1	1	3.00
Sensor, water quantity	1	0	2.00
Sensor, waste water quantity	2	0	1.00
Tank, waste water storage	1	0	60.00
Sensor, temperature H ₂ O	2	2	0.10
Controller, heater	2	1	0.50
Conductivity meter	2	2	1.0
Orifice	1	0	0.5
Cell, reverse osmosis	1	1	24.00
Disconnect, maintenance	15	0	0.75

Cost Estimating Relationships:

The reverse osmosis system components have been grouped in seven groups, designated as I through VII, as shown in the system schematic, Figure 3. The recurring and nonrecurring CER's presented in the following paragraphs are based on estimated January 1972 dollars. The consumer price index was used to adjust CER's developed and based on prior years' dollar values.

Recurring CER's:

1. Waste Water Accumulator

The waste accumulator CER is given as follows:

$$\text{Waste water accumulator fabrication cost } C = 1918V^{0.377} + 2959 W_{OC} \text{ dollars}$$

where,

$$V = \text{volume of the accumulator} = 3.5 \text{ ft}^3, \text{ and}$$

$$W_{OC} = \text{weight of other components} = 6.5 \text{ lbs}$$

The other components denote the valves associated with the operation of the accumulator. An assembly integration factor is used at the assembly level to account for necessary piping and packaging.

Substituting the values the variables in the above equation yields:

$$C = 1,918 \times 1.605 + 2959 \times 6.5 = 22,312 \text{ dollars}$$

2. High Pressure Pump Assembly

The high pressure pump assembly, which comprises the pump, filter and associated valves, has the following CER:

$$\text{High pressure pump assembly cost } C = 91 P_W^{0.942} + 670 W_{OC} \text{ dollars}$$

where,

$$P_W = \text{electrical power input to transfer pumps} = 65 \text{ watts,}$$

$$W_{OC} = \text{weight of other components} = 8.95 \text{ lbs}$$

Substituting the values of the above variables in the pump fabrication cost equation results in the following:

$$C = 91 \times 65^{0.942} + 670 \times 8.95 = 10,683 \text{ dollars}$$

3. Accumulator

The CER utilized for the accumulator is given as follows:

$$\text{Accumulator fabrication cost } C = 1,918V^{0.267} + 2959 W_{OC} \text{ dollars}$$

where,

$$V = \text{volume of accumulator} = 0.5 \text{ ft}^3,$$

$$W_{OC} = \text{weight of other components} = 1.1 \text{ lbs}$$

Substituting the above values in the tank's fabrication cost equation results in the following:

$$C = 1598 + 3255 = 4853 \text{ dollars}$$

4. Recirculation Pump

The recirculation pump assembly CER is given by the following:

$$\text{Recirculation pump fabrication cost } C = 91 P_W^{0.942} + 670 W_{OC} \text{ dollars}$$

where,

$$P_W = \text{electrical power input to transfer pumps} = 50 \text{ watts},$$

$$W_{OC} = \text{weight of other components} = 4.7 \text{ lbs}$$

Substituting the values of the above variables in the pump fabrication cost equation results in the following:

$$C = 3640 + 3149 = 6789 \text{ dollars}$$

5. Reverse Osmosis Module

The reverse osmosis cell CER is given by the following:

$$\text{Reverse osmosis module fabrication cost } C = 250 W_{RO} + 670 W_{OC} \text{ dollars}$$

where,

$$W_{RO} = \text{reverse osmosis module weight} = 24 \text{ lbs and},$$

$$W_{OC} = \text{associated components weight} = 6.35 \text{ lbs}$$

Substituting the values of variables in the above CER yields:

$$C = 6000 + 4255 = 10,255 \text{ dollars}$$

6. Processed Water Tank Assembly

The processed water tank assembly CER is given as follows:

Tank assembly fabrication cost $C = 1,918V^{0.267} + 2959 W_{OC}$ dollars

where,

V = volume of processed water tank = 3.5 ft^3 and,

W_{OC} = weight of other components = 16.6 lbs

Substituting the above values in the tank's fabrication cost equation results in the following:

$$C = 3078 + 49,119 = 52,197 \text{ dollars}$$

7. Controller

The CER used for the controller fabrication cost was based on CER's developed for similar equipment and is given as follows:

Controller fabrication cost $C = 4795 W$ dollars

where,

W = controller weight = 10.0 lbs

thus,

$$C = 4795 \times 10 = 47,950 \text{ dollars}$$

Integrated Reverse Osmosis System's Recurring CER:

The integration costs of components and assemblies into the reverse osmosis system are obtained by utilizing the total system's recurring CER as defined in previous sections of the report. Applying the said CER, then:

$$\begin{aligned} \text{First unit cost } C_F &= 1.833 \times 1.1 \times (22,312 + 10,683 + 4853 + 6789 \\ &\quad + 10,255 + 52,197 + 47,950) \\ &= 2.016 \times 155,039 = 312,600 \text{ dollars} \end{aligned}$$

and, assuming the production of two flight-type units, one for flight and one backup unit, then the total hardware recurring cost is given by:

$$C_T = 312,600 \times (2)^{1-0.1047} = 581,440 \text{ dollars}$$

Integrated Reverse Osmosis System's Non-Recurring CER's:

Non-recurring CER's have been developed for engineering design only. Other non-recurring cost estimates are based on the cost breakdown ratios utilized in the

Case of the molecular sieves system which have been based on actual cost data collected in NAS9-9018 study. The analysis of a number of cost influencing parameters indicated that engineering design CER is mainly a function of the number of component types (N) in each system and is given by the following relation.

$$\text{System design cost} = 34,935N + 102,942 \text{ dollars}$$

The regenerable solid desiccant system comprises 25 component types as shown in Table IV. Accordingly, system design cost $C = 873,375 + 102,942 = 976,317$ dollars.

Values of other non-recurring cost items are listed in Table V, which also shows the breakdown of recurring cost items based on the production of two flight hardware units. All cost figures are in estimated January 1972 dollars.

TABLE V - REVERSE OSMOSIS SYSTEM COST BREAKDOWN

Non-Recurring		Recurring	
System Engineering Design	976,317	Flight Hardware Production (2 units)	317,234
Subcontractor General and Administrative	504,759	Subcontractor G&A	53,609
Subcontractor Fee	211,861	Subcontractor Fee	22,560
Program Management	73,224	Program Management	7,908
System Engineering	307,540	Sustaining Engineering	11,396
Development Test	201,121		
Qualification Test	148,400		
Reliability Test	239,198		
AGE	1,079,807		
Tooling	226,506	Sustaining Tooling	9,826
Non-accountable Test Hard- ware	97,632		
Specifications, Vendor Coordination and Procure- ment Expense	797,651	Specifications, Vendor Coordination and Procure- ment Expense	90,065
System Integration	489,135	System Integration	41,573
Prime's Testing	478,395		
Minor Subcontracts	22,455	Minor Subcontracts	27,269
Total	5,854,001		581,440

Total Reverse Osmosis System Cost = 5,854,001 + 581,440 = 6,435,441 dollars

3.3 MULTIFILTRATION WASH WATER SYSTEM:

System Description:

The Multifiltration Wash Water Subsystem, shown schematically in Figure 4, includes the following major components and/or assemblies:

- (1) Multifiltration unit consisting of a 30-micron, a 3-micron, and a 1-micron filters, two activated charcoal filters, a mixed resin column and a "cation" resin column.
- (2) A receiving tank, an on-line tank and a reserve tank.
- (3) A circulation pump.
- (4) Valves, sensors and controls.
- (5) A water chiller.

A complete listing of all the wash water subsystem components is given in Table VI. The multifiltration wash water system performance and design requirements are as follows:

Whole Body Shower Water Process Rate =	144 lbs/day
Hand Wash Water Process Rate =	12 lbs/day
Housekeeping Water Process Rate =	8 lbs/day
Process Water Temperature =	165 \pm 5°F

System operation and control as well as individual component design and performance characteristics are discussed in the following:

Operation

The heated positive expulsion tanks shown on the right side of the water system schematic, Figure 4, are sized for the 24-hour use rate which is 164 lbs or 19.7 gallons (6 man) of usable water. A multifiltration unit is combined with a line receiver to limit the filtration unit rate to 6.8 lb/hr. Electric 3-way valves are incorporated into the tank expulsion system such that each

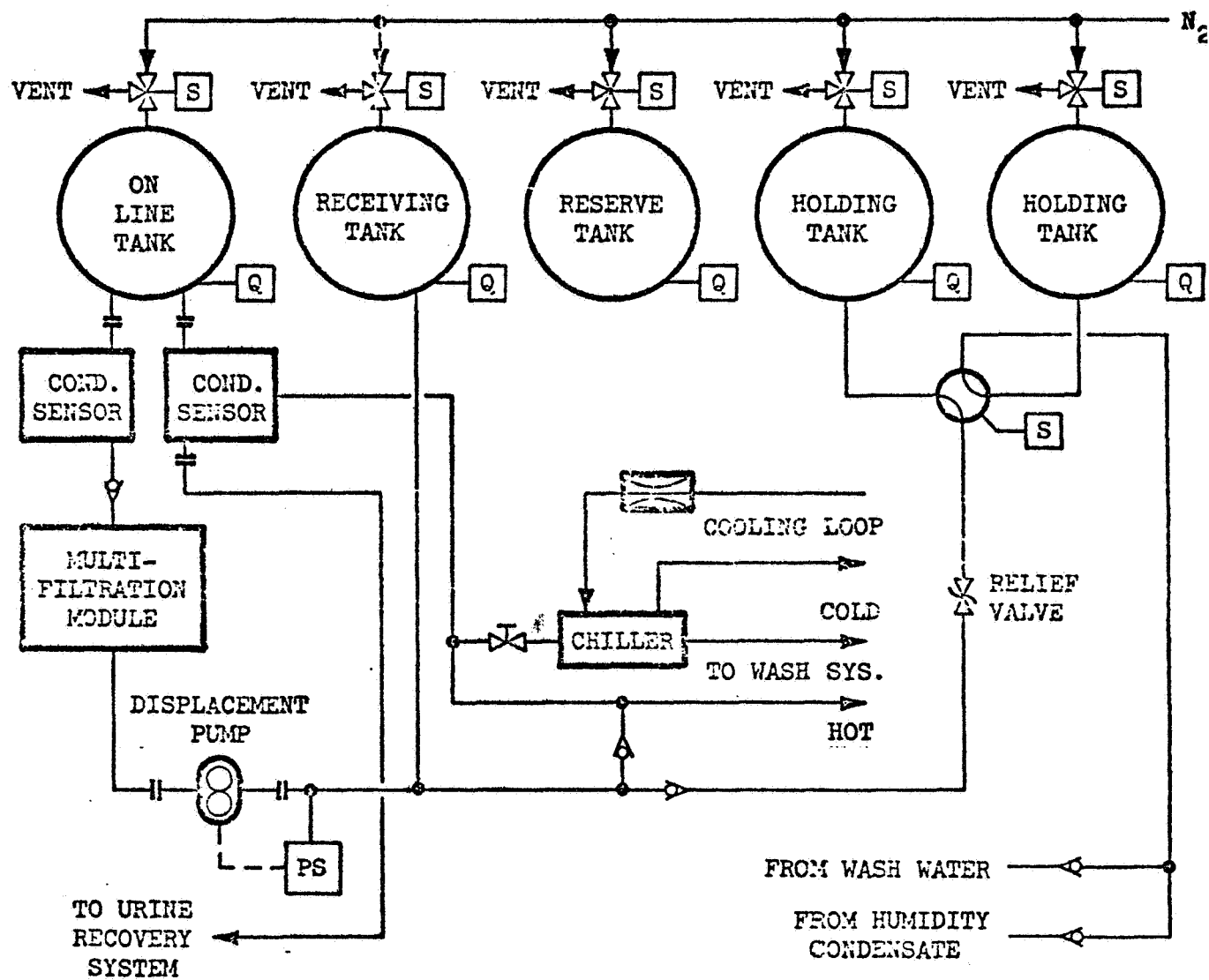


FIGURE 4. WASH WATER MULTIFILTRATION SYSTEM

TABLE VI

MULTIFILTRATION WASH WATER RECOVERY SYSTEM COMPONENTS LISTING

COMPONENT	QUANTITY	SPARES	UNIT WEIGHT (LBS.)	TOTAL WEIGHT (LBS.)
Valve, Vent, 3-Way Solenoid	5	2	3	21.0
Valve, Liquid, 4-Way Solenoid	1	1	3	6.0
Valve, Check	4	1	1	5.0
Valve, Relief, 40 PSIG	1	1	1.5	3.0
Orifice	1	0	1	1.0
Quick Disconnect, Liquid	15	3	0.5	9.0
Quantity Sensor	5	1	1.0	6.0
Pressure Switch	1	1	1.5	3.0
Pump	1	1	2.0	4.0
Chiller	1	0	5.0	5.0
Valve, Manual	1	1	1	2.0
Tanks	5	0	25.0	125.0
Multifiltration Module	1	9 ⁽¹⁾	18	180.0
Cleansing Agent Tank	1 ⁽²⁾	0	2.0	2.0
Sensor, Temperature	1	2	0.2	0.6
Controller, Wash Water Temperature	1	1	1.0	2.0
Septum	2	0	1	2.0

NOTES: (1) Included are 8 expendable multifiltration cartridges required for 180-day mission.

(2) Additionally, 16 lbs of cleansing agent are required for the 180-day mission.

tank can be vented, connected to the pressurizing gas supply or cut off. Normal operation places all three tanks on the pressure gas line. Water is circulated by the positive displacement pump at all times. A high inlet pressure differential to the bypass valve opens the hot supply line to the return line. This allows a circulation of hot water to keep the lines free of microbial growth. A chiller is provided to reduce the temperature of 45°F for cold water use. Three tanks are provided, one of which is filled and on standby. When the water degrades to the point that reprocessing is desirable, the standby and use tanks are switched and the water outlet of the other tank is switched to the urine recovery system inlet for reprocessing. This water is processed when the urine feed is off, collected in potable water use tanks and then returned to the standby wash water tank.

Control

System controls utilize a centralized control panel. The multifiltration wash water panel can be mounted near its tanks, since it requires no attention except for reprocessing wash water, or also could be located in the waste management compartment. Quality gages and tank pressure data are available for system checks and analysis. All switches are normally in the ON position and periodic operations are not required. Should the water require reprocessing, the quick-disconnect hoses are switched to the other supply tank after verifying that the receiver is empty, and the urine recovery system line is connected to the unacceptable tank. Water is returned to the wash water system after processing through the potable water system by use of the other hose. Water transfer to and from receiving tanks and use tanks is accomplished through the use of quick-disconnects, rather than valved connectors, in order to minimize the possibility of bacteria growth or migration through the water lines.

The tank connectors are flexible hoses on the panels with quick disconnects and are advanced in a circular clockwise direction. Quantity gages allow a visual assessment of tank condition. By placing the interconnect panels in a protected location there is no possibility of inadvertent crew contact on the looped hoses and location in the waste management compartment minimizes

crew time in going to and from the panels when the connectors are cycled. Tank heater switches are center off with #1 heater up and #2 heater down. Warning lights indicate an inoperative heater. The three way tank gas pressure valve switches have a center test position that cuts off the line and connects the particular tank sensor to the pressure gage for a check reading. A decrease of pressure on an empty tank indicates a diaphragm leak. Normal position is up for line gas pressure, down gives a vent to cabin atmosphere such as required for tank removal. Pump power switches are available for manual shutdown or removal of pumps.

Major Components

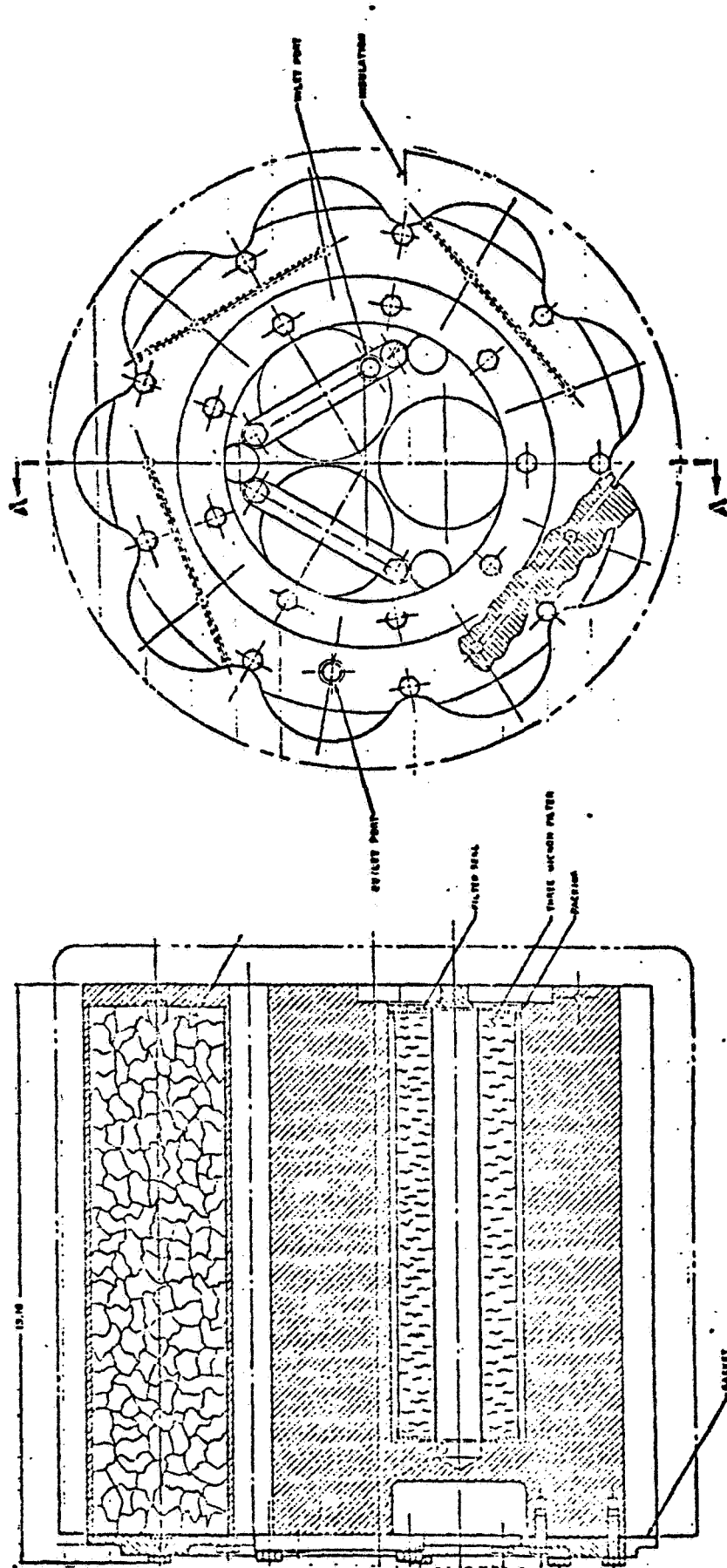
Following is a description of the major components of the multifiltration wash water system:

1. Multifiltration Module:

The wash water multifiltration module, shown in Figure 5, utilizes filtration and heat sterilization to recover water for processing water for personal hygiene purposes only, and is comprised of the following filters in series:

- a. 30μ Pall filter which weighs 0.5 lbs,
- b. 3μ Pall filter which weighs 0.5 lbs,
- c. 1μ Pall filter which weighs 0.5 lbs,
- d. Activated charcoal column, 3.0 inches in diameter, 24 inches long and containing 3.0 lbs of Barneby-Chensy activated charcoal Type P1.
- e. Dowex ARM-381 mixed resin bed column, 3.0 inches in diameter, 24.0 inches long and containing 3.0 lbs of resin.
- f. Dowex ARC-351 cation resin bed column, 3.0 inches in diameter, 24.0 inches long and containing 3.0 lbs of resin.
- g. A second activated charcoal filter identical to (d), above.

Figure 5 shows the length of each of the charcoal and resin columns divided in two halves for better packaging and handling purposes.



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Figure 5. Wash Water Multifiltration Module

The expendable required of the wash water multifiltration module based on the NASA 90-day test data, are expected to be as follows:

- a. Activated charcoal columns (a set of two), containing 5.0 lbs of charcoal, with an estimated total canister weight of 7.5 lbs for processing 4000.0 lbs of wash water.
- b. Ion exchange columns (one anion resin and one cation), containing 6 lbs of resin, with an estimated total canister weight of 7.5 lbs for processing 4000.0 lbs of wash water.
- c. Pall particulate filters (a set of one 30- μ , one 3- μ and one 1- μ filters), with a total weight of 1.5 lbs for processing 4000.0 lbs of wash water.
- d. Two pounds of cleansing agent for use with every 4000 lbs of wash water.

2. Tanks and Heaters:

The wash water tanks are spherical, 20.8 inches in diameter, with a capacity of 19.7 gallons each, and are insulated with 2 inches of glass wool. Electrical heaters are located in the tanks and are each rated at 130 watts. Hot lines are insulated sufficiently so that the hot sterilization temperatures can be maintained without the need for line heaters or booster. Losses are estimated to be a few Btu/Hr per foot of line length with a 160 - 180°F fluid temperature.

3. Pump:

A positive displacement pump, with a capacity of 0.84 GPH, is required to assure correct flow rates. Since this flow rate is about 1/30 of the flow rate of Apollo pumps, there are no qualified pumps in this flow range. Power for this pump is expected to be approximately 5 watts.

Cost Estimating Relationships:

The multifiltration system components have been grouped in four groups, designated as I through IV, as shown in the system schematic, Figure 4. The recurring and non-recurring CER's presented in the following paragraphs are based on estimated January 1972 dollars. The consumer price index was used to adjust CER's developed and based on prior years' dollar values.

Recurring CER's:

1. Potable Water Tanks

The CER utilized for the potable water tanks is given as follows:

$$\text{Tanks fabrication cost } C = 1,918V^{0.267} Q^{0.89} + 2959 W_{OC} \text{ dollars}$$

where,

$$V = \text{volume of tanks} = 2.725 \text{ ft}^3,$$

$$Q = \text{number of tanks} = 5, \text{ and}$$

$$W_{OC} = \text{weight of other components} = 30.5 \text{ lbs}$$

Substituting the above values in the tanks fabrication cost equation results in the following:

$$C = 1918 \times 1.307 \times 4.2 + 2959 \times 30.5 = 100,327 \text{ dollars}$$

2. Multifiltration Module

The CER utilized for the multifiltration module is based on costs of similar hardware and is given as follows:

$$\text{Multifiltration module fabrication cost } C = 200 W_{MF} + 670 W_{OC} \text{ dollars}$$

where,

$$W_{MF} = \text{multifiltration module weight} = 240 \text{ lbs and,}$$

$$W_{OC} = \text{weight of associated components} = 4.0 \text{ lbs}$$

Substituting the values of variables in the above CER yields:

$$C = 200 \times 24 + 670 \times 4 = 7480 \text{ dollars}$$

3. Displacement Pump

The CER for the water transfer pump is given by the following relation:

$$\text{Circulating pump fabrication cost } C = 91 P_W^{0.942} + 670 W_{OC} \text{ dollars}$$

where,

$$P_W = \text{electrical power input to pump} = 5.0 \text{ watts,}$$

$$W_{OC} = \text{weight of other components} = 3.5 \text{ lbs}$$

Substituting the values of the variables in above CER yields the following:

$$C = 91 \times 12.8 + 670 \times 3.5 = 3510 \text{ dollars}$$

4. Chiller Assembly

The chiller is basically a heat exchanger and the CER utilized for the chiller assembly is given by the following:

$$\text{Chiller fabrication cost } C = 159 W^{0.267} N_P^{1.905} + 2959 W_{OC} \text{ dollars}$$

where,

$$W = \text{chiller weight} = 5.0 \text{ lbs,}$$

$$N_P = \text{number of ports per chiller} = 4,$$

$$W_{OC} = \text{weight of associated components} = 4 \text{ lbs}$$

Substituting the values of variables in the CER yields:

$$C = 159 \times 1.539 \times 14.05 + 2959 \times 4 = 15,670 \text{ dollars}$$

Integrated Multifiltration System's Recurring CER:

The integration costs of components and assemblies into the multifiltration system are obtained by utilizing the total system's recurring CER as defined in previous sections of this report. Applying the said CER, then:

$$\begin{aligned} \text{First unit cost } C_F &= 1.833 \times 1.1 \times (100,327 + 7480 + 3510 + 15,670) \\ &= 2.016 \times 126,987 = 256,040 \text{ dollars} \end{aligned}$$

and, assuming the production of two flight-type units, one for flight and the other for backup, then the total hardware recurring cost is given by:

$$C_T = 256,040 \times (2)^{1-0.1047} = 475,722 \text{ dollars}$$

Integrated Multifiltration System's Non-Recurring CER's:

Non-recurring CER's have been developed for engineering design only. Other non-recurring cost estimates are based on the cost breakdown ratios utilized in the case of the molecular sieves system which have been based on actual cost data collected in NAS9-9018 study. The analysis of a number of cost influencing parameters indicated that engineering design CER is mainly a function of the number of component types (N) in each system and is given by the following relation.

$$\text{System design cost } C = 34,935N + 102,942 \text{ dollars}$$

The regenerable solid desiccant system comprises 18 component types as shown in Table VI. Accordingly, system design cost $C = 628,830 + 102,942 = 731,772$ dollars.

Values of other non-recurring cost items are listed in Table VII, which also shows the breakdown of recurring cost items based on the production of two flight hardware units. All cost figures are in estimated January 1972 dollars.

TABLE VII - MULTIFILTRATION SYSTEM COST BREAKDOWN

Non-Recurring		Recurring	
System Engineering Design	731,772	Flight Hardware Production (2 units)	259,554
Subcontractor General and Administrative	378,326	Subcontractor G&A	43,862
Subcontractor Fee	158,795	Subcontractor Fee	18,458
Program Management	54,883	Program Management	6,470
System Engineering	230,508	Sustaining Engineering	9,324
Development Test	150,745		
Qualification Test	111,229		
Reliability Test	179,284		
AGE	809,340		
Tooling	169,771	Sustaining Tooling	8,040
Non-accountable Test Hardware	73,772		
Specifications, Vendor Coordination and Procure- ment Expense	597,858	Specifications, Vendor Coordination and Procure- ment Expense	73,689
System Integration	366,618	System Integration	34,014
Prime's Testing	358,568		
Minor Subcontracts	16,831	Minor Subcontracts	22,311
Total	4,388,290		475,722

Total Multifiltration System Cost = 4,388,290 + 475,772 = 4,864,062 dollars

3.4 VAPOR COMPRESSION SYSTEM:

System Description:

This system is used for collecting and processing urine, urinal flush water and rejected condensate. The recovered water is used for drinking and food reconstitution. The system includes a urine collection module containing a urinal blower type phase separator. The urine collection module is actuated by removing the urinal from its holder, which closes a switch and energizes the separator motor. Cabin gas is drawn into the urinal through peripheral holes and transfers the urine to the separator by pneumatic entrainment. After micturition, silver ion dosed water enters the urinal for flushing at approximately 30 psig and 100°F. A flow of 150 ml of flush water is admitted to the urinal for approximately 10 seconds by a control timer. As this water is drawn into the separator, a measured amount of pretreatment chemical, to fix the urine, is mixed with the water. The pretreatment chemical, a compound composed of disinfectant, acid, antifoam agent, and water, is utilized at a rate of 0.4 lbs of pretreatment per 100 lbs of urine and flush water. The separator uses a rotating bowl to separate urine and flush water from cabin gas. The separated air is passed through a charcoal and bacteria filter and discharged into the cabin.

The pretreated urine and flush water are transferred from the liquid/gas separator to the waste collection tank, which has a capacity of 134 lbs of waste liquid.

The waste liquid is fed to the distillation module from the tank for processing. A peristaltic type feed pump sends liquid to the distillation module at a fixed rate of 15 lbs/hr. This pump is mounted on a common drive shaft with the recycle and condensate pumps.

The distillation unit is a motor driven, cylindrical device which separates liquids and gases by centrifugal force. Two concentric cylinders are used to form an inner evaporator and an annular condenser. The vapor compressor is statically sealed and is driven by an externally mounted motor at a rotational speed of approximately 3400 rpm. Timing gears step down the speed so that the bowl is driven by the same motor at 240 rpm. The distillation process occurs

whenever the motor is energized. The removal of water vapor concentrates the waste in the solution so that the concentration of dissolved solids is greatest at the hub end of the evaporator, which contains an annular sump.

Water vapor and gases are drawn from the evaporator through a demister into the vapor compressor and then forced into the condenser. A relief valve is located on the compression discharge to avoid any excessive pressure differentials that could cause overly vigorous boiling and to permit rapid startup with cabin gas in the condenser. Water vapor is condensed on the outer surface of the evaporator cylinder and centrifuged as droplets to the inner surface of the outer shell where it flows into an annular condensate sump. The condensate, at a nominal rate of 2.42 lbs/hr is transferred out of the condenser through two condensate pumps in series through a conductivity meter and a motor driven three-way valve.

The required start-up time for the still is approximately one hour to reach normal processing rate and the average processing rate is 2.42 lb/hr. for each still and the modules can operate continuously. If the feed is depleted, the still will continue to rotate to dry out the evaporator and prevent contamination. Normal dryout time is one to two hours.

Non-condensable gases are removed from the condenser section of the still by a purge pump and returned to the cabin. The purge flow is discharged to the urinal separator, thus taking advantage of the bacteria/charcoal filter.

Vapor compression distillation rate is directly proportional to cabin temperature and inversely proportional to the concentration of dissolved solids. The still will normally operate with the evaporator pressure at the saturation pressure of water at cabin gas temperature. The condenser temperature will be no less than 6°F above the saturation temperature of water at evaporator pressures. Normally, the evaporator pressure will be 20 mm Hg while the condenser pressure will be 40 mm Hg. The condensate water will normally be transferred to the water storage and sterilization subsystem at condenser temperature of approximately 90°F and a pressure of 30 psig.

Bacteria and odor control within this circuit is provided by the pretreatment of the urine in the urine collection module, flushing with silver dosed sterile water and distillation under vacuum at room temperature. Since the subsystem is sealed, odor control is not a problem. Gas from the separator is discharged directly to the cabin. Maintenance design is such that removal of components will not allow exposure of the contents of the circuit to the cabin atmosphere.

A flow diagram of the vapor compression system is shown in Figure 6. Table VIII gives a complete listing of the vapor compression system components.

TABLE VIII
VAPOR COMPRESSION SYSTEM
COMPONENTS WEIGHT

COMPONENT	QUANTITY	SPARES	UNIT WEIGHT (LBS)
Valve, check, liquid	6	2	0.69
Valve, shutoff, electrical	2	0	1.30
Valve, shutoff, manual	7	2	0.8
Valve, 3-way manual, vacuum	1	1	3.50
Valve, 3-way electrical, manual override	3	3	1.44
Valve, 3-way, electrical, gas	6	3	2.50
Valve, disconnect	10	1	0.8
Valve, 3-way, liquid	5	1	1.7
Filter	1	1	3.47
Filter, activated charcoal/bacteria	3	0	8.00
Separator, liquid gas	1	0	8.00
Pump assembly, still	1	3	6.00
Chiller	2	0	2.00
Heat exchanger	1	0	10.00

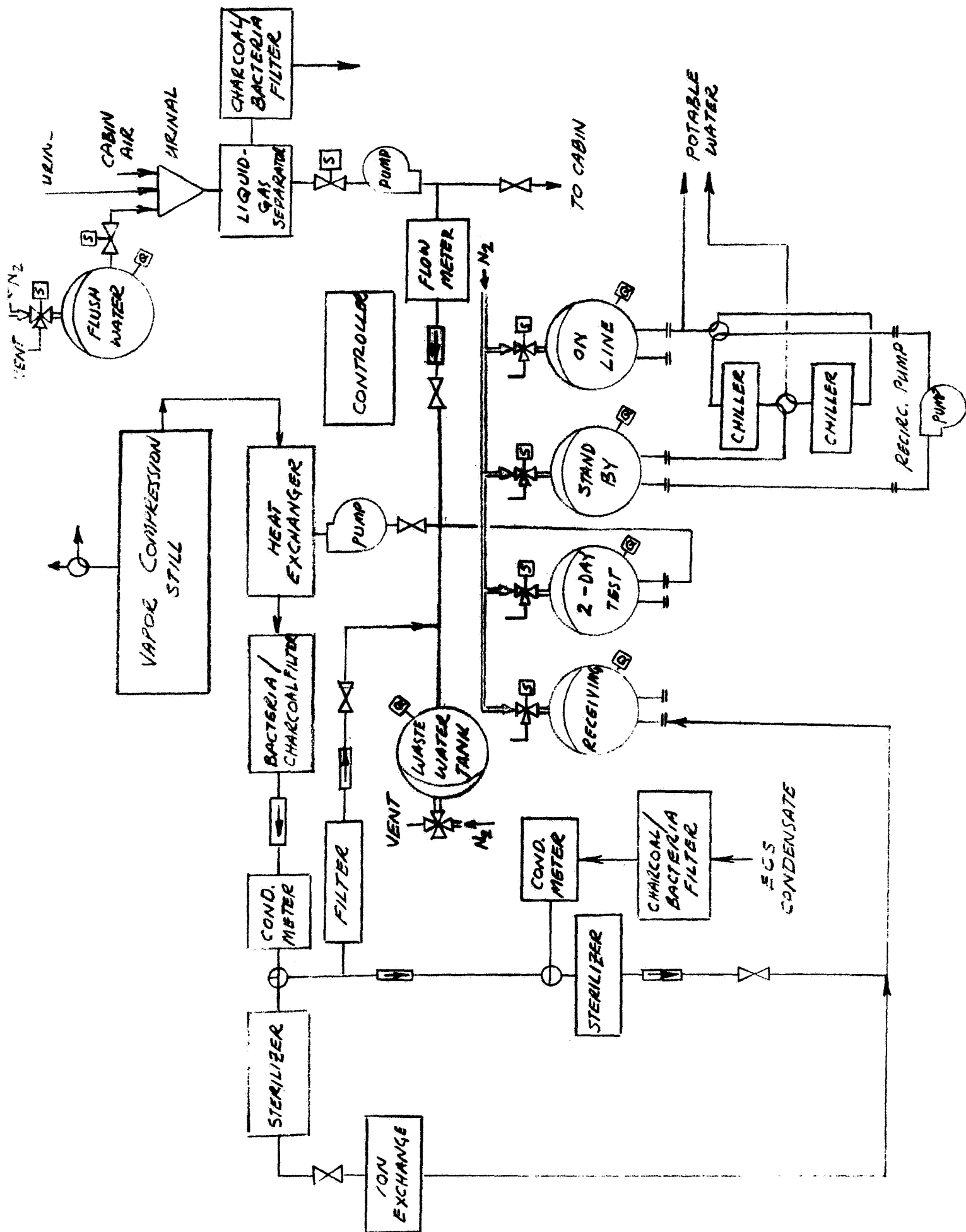


FIGURE 7 VAPOR COMPRESSION SYSTEM

TABLE VIII
VAPOR COMPRESSION SYSTEM
COMPONENTS WEIGHT
(Continued)

COMPONENT	QUANTITY	SPARES	UNIT WEIGHT (LBS)
Meter, conductivity	2	2	0.20
Controller, VCD	1	1	5.00
Sensor, potable and waste water quantity	6	4	1.00
Controller, urinal	3	1	2.50
Tank, potable and waste water storage	6	2	60.00
Still, vapor compression	1	1	75.00
Urinal	1	1	0.60
Flow meter	1	1	1.00
Sterilizer	2	1	3.70
Orifice	1	1	1.40
Measurement switching unit	1	0	15.60
Measurement unit	1	0	14.40
Filter, ion exchange	1	1	3.00

Cost Estimating Relationships:

The components utilized in the vapor compression system have been grouped into eight groups, designated as I through VIII, as shown in the system schematic, Figure 6. The recurring and non-recurring CER's presented in the following paragraphs are based on estimated January 1972 dollars. The Consumer Price Index was used to adjust CER's developed and based on prior years' dollar values.

1. Potable and Waste Water Tanks

The CER for the potable and waste water tanks is given as follows:

Tanks fabrication cost $C = 1,918V^{0.267}Q^{0.89} + 2959 W_{OC}$ dollars

where,

V = volume of tanks = 3.0 ft^3

Q = number of tanks = 6, and

W_{OC} = weight of other components = 22.3 lbs

Substituting the above values in the tanks' fabrication, cost equation results in the following:

$$C = 1,918 \times 1.342 \times 4.92 + 2959 \times 22.3 = 78,645 \text{ dollars}$$

2. Urinal and Gas Separator

The urinal and gas-liquid separator CER is given by the following relation:

Urinal and separator assembly fabrication cost $C = 91 P_W^{0.942} + 670 (W_U + W_{OC})$ dollars

where,

P_W = power input to separator = 200 watts,

W_U = Urinal weight = 0.6 lbs, and

W_{OC} = associated components weight = 1.0 lb

Substituting the values of variables in the above CER yields the following:

$$C = 91 \times (200)^{0.947} + 670 \times 1.6 = 14,540 \text{ dollars}$$

3. Waste Water Transfer Pump

The waste water transfer pump CER is given by the following relation:

Pumps fabrication cost $C = 91 P_W^{0.942} + 670 W_{OC}$

where,

P_W = electrical power input to transfer pumps = 30 watts,

W_{OC} = weight of other components = 4.2 lbs

Substituting the values of the above variables in the pumps fabrication cost equation results in the following:

$$C = 91 \times (30)^{0.942} + 670 \times 4.2 = 5044 \text{ dollars}$$

4. Sterilizers and Filters

The CER utilized for the sterilizers and filters is based on costs of similar hardware and is given as follows:

$$\text{Sterilizer and filters fabrication cost } C = 200 W + 670 W_{OC} \text{ dollars}$$

where,

W = weight of sterilizers and filters = 21.9 lbs, and

W_{OC} = other components weight = 4.0 lbs

Substituting the values of variables in the above CER yields:

$$C = 200 \times 21.9 + 670 \times 4.0 = 7060 \text{ dollars}$$

5. Vapor Compression Still

The CER utilized for the vapor compression still was based on manufacturers' data, as well as on comparisons with similar hardware costs, and is given as follows:

$$\text{Still fabrication cost } C = 2700 W_S + 670 W_{OC} \text{ dollars}$$

where,

W_S = vapor compression still weight = 75.0 lbs, and

W_{OC} = other components weight = 3.5 lbs

Substituting the values of variables in the above CER yields:

$$C = 2700 \times 75 + 670 \times 3.5 = 204,845 \text{ dollars}$$

6. Heat Exchanger

The regenerative heat exchanger CER is given by the following:

$$\text{Heat exchanger fabrication cost } C = 159 W^{0.267} N_P^{1.905} + 2959 W_{OC} \text{ dollars}$$

where,

W = heat exchanger weight = 10.0 lbs,

N_P = number of ports per heat exchanger = 4,

W_{OC} = weight of other components = 2.3 lbs

Substituting the values of the variables in the CER yields:

$$C = 159 \times 1.85 \times 14.05 + 2959 \times 2.3 = 10,940 \text{ dollars}$$

7. Controller

The vapor compression system controller CER is given as follows:

Controller fabrication cost $C = 4795 (W + W_{OC})$ dollars

where,

W = controller weight = 5.0 lbs, and

W_{OC} = other components weight = 30.0 lbs

Substituting the values of the variables in the above equation results in the following:

$$C = 4795 (5 + 30) = 167,825 \text{ dollars}$$

8. Chillers

The chillers CER is given by the following:

Chillers fabrication cost $C = 159W^{0.267}N_P^{1.905}Q^{0.89} + 2959W_{OC}$ dollars

where,

W = chiller weight = 2.0 lbs,

N_P = number of ports per chiller = 4,

Q = number of chillers = 2, and

W_{OC} = weight of associated components = 6.5 lbs

Substituting the values of variables in the CER yields:

$$C = 159 \times 1.204 \times 14.05 \times 1.855 + 2959 \times 6.5 = 24,223 \text{ dollars}$$

9. Circulating Pump

The CER for the water distribution system circulating pump is given by the following relation:

$$\text{Circulating pump fabrication cost } C = 91P_W^{0.942} + 670 W_{OC} \text{ dollars}$$

where,

$$P_W = \text{electrical power input to pump} = 60 \text{ watts,}$$

$$W_{OC} = \text{weight of other components} = 1.6 \text{ lbs}$$

Substituting the values of the variables in above CER yields the following:

$$C = 91 \times 48 + 670 \times 1.6 = 5440 \text{ dollars}$$

Integrated Vapor Compression System's Recurring CER:

The integration costs of components and assemblies into the vapor compression system are obtained by utilizing the system's recurring CER as defined in previous sections of this report. Applying the said CER, then:

$$\begin{aligned} \text{First unit cost } C_F &= 1.833 \times 1.1 \times (78,645 + 14,540 + 5,044 + 7,060 + \\ &\quad 204,845 + 10,940 + 167,825 + 24,223 + 5,440) = 2.016 \\ &\quad \times 518,562 = 1,045,577 \text{ dollars} \end{aligned}$$

and assuming the production of two flight-type units, one for flight and the other for back-up, then the total hardware cost is given by:

$$C_T = 1,045,577 \times (2)^{1-0.1047} = 1,944,770 \text{ dollars}$$

Integrated Vapor Compression System's Non-Recurring CER's:

Non-recurring CER's have been developed for engineering design only. Other non-recurring cost estimates are based on the cost breakdown ratios utilized in the case of the molecular sieves system which have been based on actual cost data collected in NAS9-9018 study. The analysis of a number of cost influencing parameters indicated that engineering design CER is mainly a function of the number of component types (N) in each system and is given by the following relation:

$$\text{System design cost } C = 34,935N + 102,942 \text{ dollars}$$

The regenerable solid desiccant system comprises 27 component types as shown in Table VIII. Accordingly, system design cost $C = 943,245 + 102,942 = 1,046,187$ dollars.

Values of other non-recurring cost items are listed in Table IX, which also shows the breakdown of recurring cost items based on the production of two flight hardware units. All cost figures are in estimated January 1972 dollars.

TABLE IX - VAPOR COMPRESSION SYSTEM COST BREAKDOWN

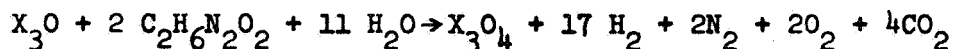
Non-Recurring		Recurring	
System Engineering Design	1,046,187	Flight Hardware	1,061,066
Subcontractor General and Administrative	540,879	Subcontractor G&A	179,308
Subcontractor Fee	227,023	Subcontractor Fee	75,457
Program Management	78,464	Program Management	26,449
System Engineering	329,549	Sustaining Engineering	38,117
Development Test	215,515		
Qualification Test	159,020		
Reliability Test	256,316		
AGE	1,157,083		
Tooling	242,715	Sustaining Tooling	32,867
Non-accountable Test Hardware	104,619		
Specifications, Vendor Coordination and Procurement Expense	854,735	Specifications, Vendor Coordination and Procurement Expense	301,245
System Integration	524,140	System Integration	139,051
Prime's Testing	512,632		
Minor Subcontracts	24,062	Minor Subcontracts	91,210
Total	6,272,939		1,944,770

Total vapor compression system cost = 6,272,939 + 1,944,770 = 8,217,709 dollars

3.5 CLOSED AIR EVAPORATION SYSTEM WITH ELECTROLYTIC PRETREATMENT

Process Description:

A flow diagram of the closed air evaporation system with electrolytic pretreatment is shown in Figure 7. The system has two primary recirculation loops. The first loop contains the electrolytic pretreatment cell that removes organic constituents from the circulating urine. The second loop contains the closed air evaporation system that removes the remaining inorganic constituents. The system achieves its self-sterilizing feature by electrolytically generating chlorine from urine. Some of the chlorinated urine is used as flush water and added to the incoming raw urine to render it stable with respect to gross microbial growth. The subsequent removal of dissolved urine solids is accomplished in two steps. In the first step, the urine and flush water mixture is electrolyzed and, through a series of electrochemical reactions, the dissolved organic materials are converted to hydrogen, nitrogen, carbon dioxide, and oxygen. In the second step, the remaining solids are removed by air evaporation system wicks. The overall electrochemical reaction for the electrolytic urine pretreatment process is approximately represented as follows:



In this equation, X_3O represents the inorganic compounds in raw urine, $C_2H_6N_2O_2$ represents the organic compounds in raw urine, and X_3O_4 represents the inorganic compounds in electrolyzed urine. X represents all atoms other than C, H, N, and O and is considered to have an atomic weight of approximately 30, which is about average for real human urine.

The mechanism for the overall electrochemical reaction is not known. However, it is felt that chemical reactions involving hypochlorite, chlorate, perchlorate, and perhaps both nascent chlorine and nascent oxygen are of prime importance. In actual practice, a batch of urine consisting of approximately 4 liters is circulated through an electrolysis cell operating at a current density in the range 200 to 300 mA/cm² until the TOC (Total Organic Carbon), COD (Chemical Oxygen Demand), and TKN (Total Kjeldahl Nitrogen) are each reduced to less than 100 mg/l.

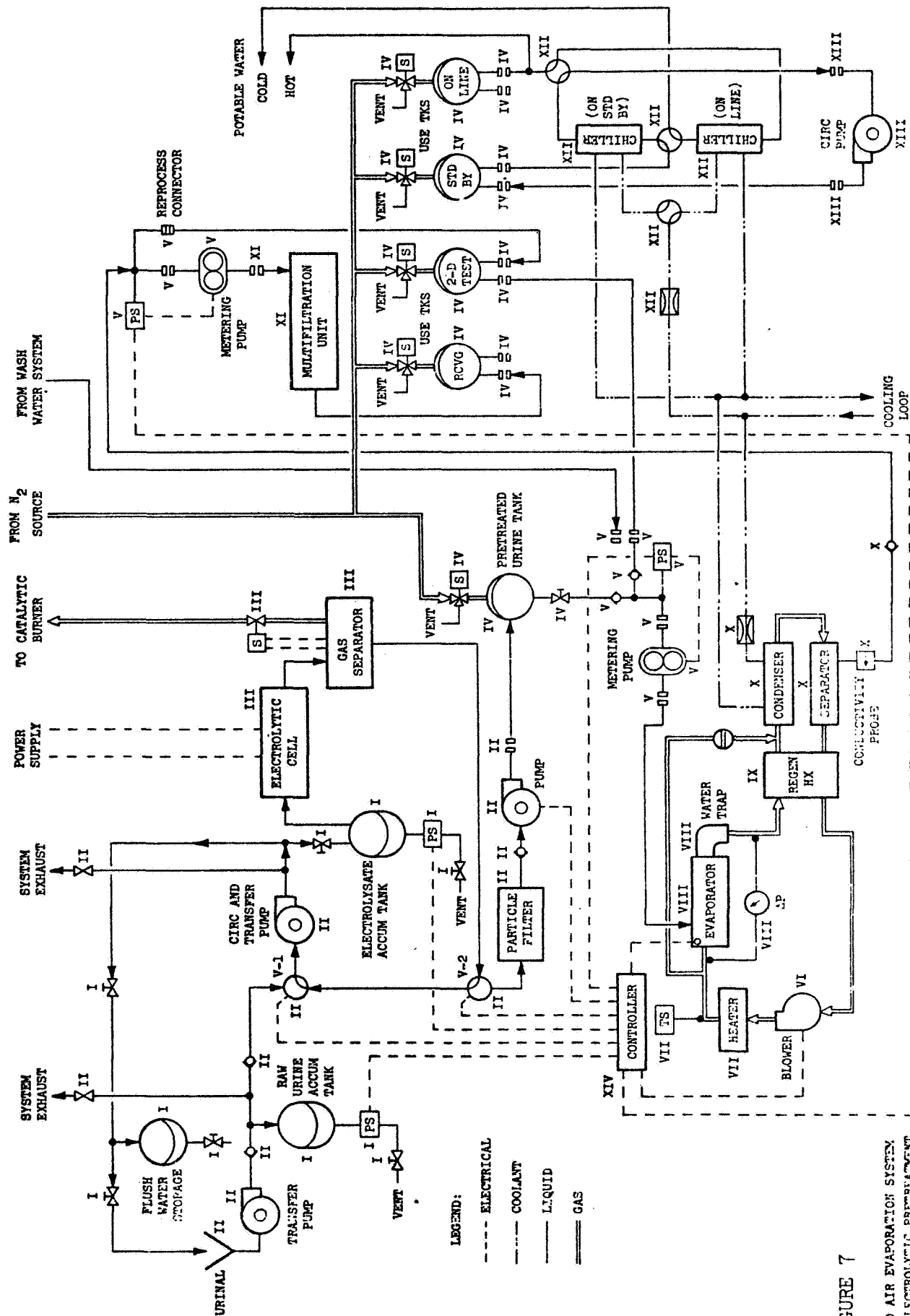


FIGURE 7

CLOSED AIR EVAPORATION SYSTEM
WITH ELECTROLYTIC PRETREATMENT

The system operation includes urine processing 4-liter batches in the electrolysis loop which on completion are transferred to the air evaporation loop. When a batch is completed in the air evaporation loop, the resulting purified water is transferred to the potable water storage tanks. The subsystem also has a pretreated urine accumulator and a flush water storage tank. The flush water tank has a manual fill provision to enable experimental determination of the optimum point at which flush water should be extracted in the electrolysis cycle. All other operations are completely automatic and function as described in the following paragraphs.

Four distinct pressure plateaus are arranged in the subsystem so that internal leakage will cascade in a reverse direction from: 1) the potable water storage tank, to 2) the air evaporation loop, to 3) the electrolysis loop, to 4) the raw urine accumulator. The pressure in each part of the subsystem is a function of the initial pressure loading in the individual bladder tanks. The pressure levels are set to eliminate overlap at the high- and low-pressure end of each plateau.

When a batch of pretreated urine is available in the pretreated urine accumulator, shown in Figure 1, and the electrolysis loop has completed its previous batch, valve V-1 moves to admit raw urine to the electrolysis loop. The transfer pump transfers raw urine into the electrolysate accumulator until the raw urine accumulator is emptied. Valve V-1 then moves to the position for circulating in the electrolysis loop.

When the electrolysis loop completes a batch, as determined by a preset timer, and the air evaporation loop has completed its previous batch, valve V-2 moves to admit the semi-processed urine from the electrolysis loop to the air evaporation loop. The semi-processed urine is then pumped into the pretreated urine holding tank until the electrolysate accumulator is emptied. Valve V-2 then returns to its normal position and processing in the air evaporation loop is started. If after completion of this operation there is another batch of electrolysate ready for processing, it is automatically transferred and processed. If no electrolysate is available, the air evaporation loop automatically shuts down and waits for the next batch. The electrolysis loop is automatically controlled in a similar manner in respect to availability of raw urine.

In the closed air evaporation loop, impure water is fed into a wick material through which heated air is passed. The combined action of reduced vapor pressure and heat transfer from the air to the water rapidly evaporates the water in the wick leaving the residues behind. The closed circuit air system comprises a blower and an isotope heater, both adding energy to the air stream, followed by the wick evaporator which extracts the heat of vaporization from the air stream. The vapor-laden air then passes through a regenerative heat exchanger which is used to extract heat from the air leaving the evaporator and adds it to the air leaving the condenser/separator. After leaving the heat exchanger, the air stream is admitted to the condenser/separator where the condensed water is extracted. When the wick is saturated with residues, it is taken off the line and replaced with a new wick. The isotope heater is designed to supply the system with a constant thermal load of 700 watts.

The closed air evaporation loop has inlets from the electrolysis system and transfer lines from the wash water and potable water systems to allow reprocessing of unacceptable water. A metering pump supplies 4.0 lb/hr of pretreated urine or wash water to the evaporator as long as a supply is present at the inlet. The evaporator has two wick assemblies which permit switching of the process path to allow wick replacement while maintaining continuous operation. Normal usage allows the maximum quantity of urine to be processed in approximately 16 hrs/day and thus leaves 8 hrs/day available for maintenance or water reprocessing.

The multifiltration unit and metering pump are designed for a flow rate of 4.2 lb/hr which allows the reprocessing of an out-of-tolerance potable tank (requires 2 days) or a wash water tank (requires 12 days) without interruptions in service. Note that potable use tank reprocess water comes into the system either ahead of the multifiltration unit pump or with the wash water through the evaporator inlet line.

There are 4 use tanks with positive expulsion system and solenoid-controlled 3-way valves and each with a capacity of 23.2 gallons. One tank is receiving, one is on the 2-day test cycle, one is on standby with chiller sterilization, and one on line for crew use. A three-section electric or pneumatic valve is used to switch chillers from use to standby recirculation when use tanks are

switched. This provides for periodic microbe control on the chiller every 2 days. An inlet pressure controlled pump recirculates the hot water except when the inlet is dead headed. The conductivity meter monitors the wick loading, with the high reading (1700 micro mhos/cm) indicating the end of useful wick life.

A complete listing of components in the closed air evaporation system with electrolytic pretreatment is shown in Table X. Expendable filters and evaporators are included as spares for a 6-man/180-day mission.

TABLE X - AIR EVAPORATION/ELECTROLYTIC PRETREATMENT SYSTEM COMPONENT LIST

COMPONENT	QUANTITY	SPARES	UNIT WEIGHT (LBS)	TOTAL WEIGHT (LBS)
A. <u>Electrolytic Pretreatment Loop:</u>				
Valve, shut-off, manual	8	3	1.0	11.0
Valve, solenoid	1	1	2.0	4.0
Valve, 3-way, electrical	2	2	1.5	6.0
Valve, check	3	2	0.7	3.5
Tanks, bladder	3	3	18.0	108.0
Valve, Q.D.	1	1	0.5	1.0
Pump, liquid	3	3	3.5	21.0
Electrolytic cell	1	2	4.0	12.0
Separator, liquid/gas	1	1	3.0	6.0
Pressure switch	2	2	1.5	6.0
Filter	1	2	3.5	10.5
Urinal	1	1	0.6	1.2
Controller	1	1	15.0	30.0
Measurement switching unit	1	0	15.6	15.6
Measurement unit	1	0	14.4	14.4
Sensor, water quantity	3	4	1.0	7.0
Subtotal	30	27	-	257.2

TABLE X - AIR EVAPORATION/ELECTROLYTIC PRETREATMENT SYSTEM COMPONENT LIST
(Continued)

COMPONENT	QUANTITY	SPARES	UNIT WEIGHT (LBS)	TOTAL WEIGHT (LBS)
B. Closed Air Evaporation Loop:				
Blower	1	1	1.5	3.0
Isotope heater assembly	1	0	8.0	8.0
Evaporator, dual	2	15*	10.0	170.0
Water trap	1	0	1.5	1.5
Heat exchanger, regenerative	1	0	20.0	20.0
Condenser/separator	1	1	40.0	80.0
Elbow separator	1	0	1.5	1.5
Bladder tank, 3.4 gallons size	1	1	12.4	24.8
Bladder tank, 23.2 gallons size	4	4	60.0	480.0
Pump, dual metering	1	1	3.0	6.0
Pump, metering	1	1	2.0	4.0
Pump, circulation	3	3	3.5	21.0
Multifiltration unit	1	8*	5.0	45.0
Chiller	2	2	2.0	8.0
Valve, manual	1	1	1.0	2.0
Valve, vent, 3-way solenoid	5	3	3.5	28.0
Valve, check	3	2	0.7	3.5
Valve, 4-way	3	2	1.7	8.5
Valve, by-pass	1	1	1.5	3.0
Orifices	2	2	1.4	5.6
Quick disconnect, liquid	18	8	0.5	13.0
Quantity sensor	5	5	1.0	10.0
Pressure switch and transducer	2	2	1.5	6.0
Temperature sensor	1	1	0.1	0.2
Conductivity probe	1	2	0.2	0.6
Controller (listed under electrolytic pretreatment loop)				
Subtotal (Air Evaporation)	63	66	-	953.2
Totals	93	93	-	1210.4

* Note: Expendables based on a 6-man/180-day mission.

System Performance and Characteristics:

The physical, performance and interface characteristics of the closed air evaporation system with electrolytic pretreatment are as follows:

Crew size	= 6 men
Urine produced, average	= 3.45 lbs/man-day
Urine processing rate	= 3.23 lb/hr

Electrolytic pretreatment loop characteristics:

Urine storage tank capacity	= 43.6 lbs
Urine holding temperature	= 160°F
Urine transfer flow rate	= 12.5 lbs/min
Urine transfer time	= 3.5 min
Batch size, maximum	= 35.1
Batch temperature	= 150 to 200°F
Batch circulation flow rate	= 8 lbs/min
Pretreated water transfer flow rate	= 12.5 lbs/min
Pretreated water transfer time	= 3.5 min
Electrolytic pretreatment unit size	= 36" x 21" x 28"

Air evaporation loop:

Pretreated tank holding capacity	= 43.6 lbs
Pretreated water temperature	= 160°F
Process water flow rate	= 3.23 lbs/hr
Process air flow rate	= 53 cfm
Evaporator inlet temperature	= 200°F
Evaporator outlet temperature	= 130°F
Stored potable water temperature	= 160°F

Cost Estimating Relationships:

The components utilized in the closed air evaporation system with electrolytic pretreatment have been grouped in 14 groups, designated as I through XIV, as shown in the system schematic, Figure 7, which includes potable water tankage and distribution equipment. The recurring and non-recurring CER's presented in the following paragraphs are based on estimated January 1972 dollars. The

consumer price index was used to adjust CER's developed and based on prior years' dollar values.

Recurring CER's:

1. Electrolytic Pretreatment Loop Accumulators

The following CER was used for the raw urine, flush water and electrolysate accumulators:

$$\text{Accumulators fabrication cost } C = 1,918V^{0.267}Q^{0.89} + 2959 W_{OC} \text{ dollars}$$

where,

V = volume of accumulator, ft^3

Q = number of accumulators, and

W_{OC} = weight of other components, lbs

Substituting the values of variables in the above equation, where $V = 0.7 \text{ ft}^3$, $Q = 3$ and $W_{OC} = 12.0 \text{ lbs}$, yields:

$$C = 1,918 \times 0.91 \times 1.854 + 2959 \times 12 = 38,744 \text{ dollars}$$

2. Electrolytic Pretreatment Loop Pumps

The electrolytic pretreatment loop pump CER is given by the following relation:

$$\text{Pumps fabrication cost } C = 91 (P_{W1}^{0.942} + P_{W2}^{0.942} Q^{0.89}) 670 W_{OC}$$

where,

P_{W1} = electrical power input to circulation pump = 120 watts,

P_{W2} = electrical power input to transfer pumps = 10 watts,

Q = number of transfer pumps = 2, and

W_{OC} = weight of other components = 8.7 lbs.

Substituting the values of the above variables in the pumps fabrication cost equation results in the following:

$$C = 91 (92 + 8.8 \times 1.852) + 670 \times 8.7 = 15,684 \text{ dollars}$$

3. Electrolytic Cell Module Fabrication

A study of the costs of similar electrochemical cells and of prototype electrolytic pretreatment cells indicates that the cost of fabrication of electrolytic cell module fabrication cost may be given by the following relation:

$$C = 6250W_M + 2192 W_{OC} + 2000 \text{ dollars}$$

where,

$$W_M = \text{weight of module} = 4.0 \text{ lbs, and}$$

$$W_{OC} = \text{weight of other components} = 5.0 \text{ lbs}$$

Substituting the values of the above variables in the electrolytic cell module fabrication, cost equation yields the following:

$$C = 6250 \times 4 + 2192 \times 5 + 2000 \text{ dollars}$$

4. Pretreated Urine and Potable Water Tanks

The same CER used for the electrolytic loop accumulators is utilized for the pretreated urine and potable water tanks and is given as follows:

$$\text{Tanks fabrication cost } C = 1,918V^{0.267}Q^{0.89} + 2959 W_{OC} \text{ dollars}$$

where,

$$V = \text{volume of tanks} = 1.0 \text{ ft}^3$$

$$Q = \text{number of tanks} = 5, \text{ and}$$

$$W_{OC} = \text{weight of other components} = 27.5 \text{ lbs}$$

Substituting the above values in the tanks fabrication, cost equation results in the following:

$$C = 1918 \times 1 \times 4.2 + 2959 \times 27.5 = 89,153 \text{ dollars}$$

5. Metering Pumps

The CER for the metering pumps is given by the following equation:

$$\text{Pumps fabrication cost } C = 91 P_W^{0.942} Q^{0.89} + 670 W_{OC} \text{ dollars}$$

where,

P_W = electrical power input to transfer pumps = 10 watts

Q = number of transfer pumps = 2, and

W_{OC} = weight of other components = 7.4 watts

Substituting the values of the above variables in the pumps fabrication cost equation results in the following:

$$C = 91 \times 8.8 \times 1.852 + 670 \times 7.4 = 6,441 \text{ dollars}$$

6. Air Evaporation Loop Blower

The air blower CER is primarily dependent on the electrical power input to the unit and is given by the following relation:

$$\text{Air evaporation loop blower fabrication cost } C = 38.2 P^{0.942} \text{ dollars}$$

where,

P = blower's electrical power input = 150 watts

then,

$$C = 38.2 \times 112 = 4278 \text{ dollars}$$

7. Air Evaporation Loop Heater

An isotope type heater is used in the air evaporation loop. The heater CER reflects only the cost of the housing and support structure and not the radio-isotope elements and is given as follows:

$$\text{Air evaporation loop heater fabrication cost } C = 600 (W_H + W_{OC}) \text{ dollars}$$

where,

W_H = heater weight = 8 lbs, and

W_{OC} = other components weight = 0.1 lbs

Substituting the values of variables in the CER yields:

$$C = 600 (8 + 0.1) = 4860 \text{ dollars}$$

8. Evaporator

The evaporator CER, given below, was formulated by evaluating the unit structure and comparing it to other CER's developed for heat exchangers and canisters,

and is given as follows:

$$\text{Evaporator fabrication cost } C = 15,865 W^{0.267} + 2959 W_{OC} \text{ dollars}$$

where,

W = evaporator weight = 10.0 lbs, and

W_{OC} = weight of associated components = 1.7 lbs

Substituting the values of variables in the CER yields:

$$C = 15,865 \times 1.85 + 2959 \times 1.7 = 34,380 \text{ dollars}$$

9. Heat Exchanger

The air evaporation loop regenerative heat exchanger CER is given by the following:

$$\text{Heat exchanger fabrication cost } C = 159 W^{0.267} N_P^{1.905} + 2959 W_{OC} \text{ dollars}$$

where,

W = heat exchanger weight = 20.0 lbs,

N_P = number of ports per heat exchanger = 4,

W_{OC} = weight of other components = 1.5 lbs

Substituting the values of the variable in the CER yields:

$$C = 159 \times 2.228 \times 14.05 + 2959 \times 1.5 = 9417 \text{ dollars}$$

10. Condenser/Separator

The CER for the air evaporation loop condenser/separator will utilize the heat exchanger relation for the condenser and assume the separator to be part of the associated components, W_{OC} . The condenser/separator fabrication cost is equation given as follows:

$$C = 159 W^{0.267} N_P^{1.905} + 2959 W_{OC} \text{ dollars}$$

where,

W = condenser weight = 16.0 lbs,

N_P = number of ports per condenser = 4,

W_{OC} = weight of other components = 5.5 lbs

Substituting the values of variables in the CER yields:

$$C = 159 \times 2.1 \times 14.05 + 2959 \times 5.5 = 20,967 \text{ dollars}$$

11. Multifiltration Unit

The CER utilized for the multifiltration unit is based on costs of similar hardware and is given as follows:

$$\text{Multifiltration unit fabrication cost } C = 200 W_{MF} + 670 W_{OC} \text{ dollars}$$

where,

$$W_{MF} = \text{multifiltration unit weight} = 5.0 \text{ lbs, and}$$

$$W_{OC} = \text{weight of associated components} = 0.1 \text{ lbs}$$

Substituting the values of variables in the above CER yields:

$$C = 200 \times 5.0 + 670 \times 0.1 = 1067 \text{ dollars}$$

12. Chillers

The chillers are basically heat exchangers and their CER is given by the following:

$$\text{Chillers fabrication cost } C = 159 W^{0.267} N_P^{1.905} Q^{0.89} + 2959 W_{OC} \text{ dollars}$$

where,

$$W = \text{chiller weight} = 2.0 \text{ lbs,}$$

$$N_P = \text{number of ports per chiller} = 4,$$

$$Q = \text{number of chillers} = 2, \text{ and}$$

$$W_{OC} = \text{weight of associated components} = 6.5 \text{ lbs}$$

Substituting the values of variables in the CER yields:

$$C = 159 \times 1.204 \times 14.05 \times 1.855 + 2959 \times 6.5 = 24,223 \text{ dollars}$$

13. Circulating Pump

The CER for the water distribution system circulating pump is given by the following relation:

Circulating pump fabrication cost $C = 91P_W^{0.942} + 670 W_{OC}$ dollars

where,

P_W = electrical power input to pump = 60 watts,

W_{OC} = weight of other components = 1.0 lb

Substituting the values of the variables in above CER yields the following:

$$C = 91 \times 48 + 670 \times 1 = 5038 \text{ dollars}$$

14. Controller

The air evaporation/electrolytic pretreatment controller CER is given by the following equation:

Controller fabrication cost $C = 4795 (W + W_{OC})$ dollars

where,

W = controller weight = 10 lbs, and

W_{OC} = other components weight = 30 lbs

Substituting the values of the variables in the above equation results in the following:

$$C = 4795 (10 + 30) = 191,800 \text{ dollars}$$

Integrated Air Evaporation/Electrolytic Pretreatment System's Recurring CER:

The integration costs of components and assemblies into the air evaporation/electrolytic pretreatment system are obtained by utilizing the system's recurring CER as defined in previous sections of the report. Applying the said CER, then:

$$\begin{aligned} \text{First unit cost } C_F &= 1.833 \times 1.1 \times (38,744 + 15,684 + 37,960 + 89,153 + \\ &\quad 6,441 + 4278 + 4860 + 34,380 + 9417 + 20,967 + \\ &\quad 1067 + 24,223 + 5038 + 191,800) = 488,562 \text{ dollars} \end{aligned}$$

and assuming the production of two flight-type units, one for flight and the other for back-up, then the total hardware recurring cost is given by:

$$C = 488,562 \times (2)^{1-0.1047} = 908,725 \text{ dollars}$$

Integrated Air Evaporation/Electrolytic Pretreatment System's Non-Recurring CER's:

Non-recurring CER's have been developed for engineering design only. Other non-recurring cost estimates are based on the cost breakdown ratios utilized in the case of the molecular sieves system which have been based on actual cost data collected in NAS9-9018 study. The analysis of a number of cost influencing parameters indicated that engineering design CER is mainly a function of the number of component types (N) in each system and is given by the following relation:

$$\text{System design cost } C = 34,935N + 102,942 \text{ dollars}$$

The regenerable solid desiccant system comprises 36 component types as shown in Table X. Accordingly, system design cost $C = 1,257,660 + 102,942 = 1,360,602$ dollars.

Values of other non-recurring cost items are listed in Table XI, which also shows the breakdown of recurring cost items based on the production of two flight hardware units. All cost figures are in estimated January 1972 dollars.

TABLE XI - AIR EVAPORATION/ELECTROLYTIC PRETREATMENT SYSTEM COST BREAKDOWN

Non-Recurring		Recurring	
System Engineering Design	1,360,602	Flight Hardware Production (2 units)	494,164
Subcontractor General and Administrative	703,431	Subcontractor G&A	83,508
Subcontractor Fee	295,251	Subcontractor Fee	35,142
Program Management	102,045	Program Management	12,318
System Engineering	428,590	Sustaining Engineering	17,752
Development Test	280,284		
Qualification Test	206,812		
Reliability Test	333,347		
AGE	1,504,826		
Tooling	315,660	Sustaining Tooling	15,307
Non-accountable Test Hardware	136,060		
Specifications, Vendor Coordination and Procurement Expense	1,111,612	Specifications, Vendor Coordination and Procurement Expense	140,297
System Integration	681,662	System Integration	64,759
Prime's Testing	666,695		
Minor Subcontracts	31,294	Minor Subcontracts	42,478
Total	8,158,171		905,725

Total air evaporation/electrolytic pretreatment system cost = 8,158,171 + 905,725
= 9,063,896 dollars

Section 4

PROTOTYPE COST ESTIMATING

The assessment of prototype hardware performance in simulated manned experiments were found to be essential in the advancement of life support technology. A working prototype is construed to have the same degree of hardware sophistication as a flight article but does not require ground support or qualification and reliability testing. Additionally, no tooling, test hardware or prime contractor integration are required. Figure 8, obtained from the results of study NAS9-9018, shows the categories and approximate percentage distribution for representative life support components. The cost of an operational prototype would be exclusive of qualification test, reliability test, AGE, test hardware, tooling, G&A, fee and prime contractor costs, as depicted in Figure 9.

In addition to the exclusion of the major cost items mentioned above, the data in NAS9-9018 indicated that in analyzing development/cost overlays with respect to the status of design at the delivery of the first test unit, approximately 38% of the design cost has been expended at this point in time. Applying this factor to Engineering Design, Development Test, Program Management, and System Engineering results in an approximate cost of a flight prototype unit. That percentage cost is as follows:

	%
1. Engineering Design	4.8
2. Program Management	0.4
3. System Engineering	1.5
4. Development Testing	1.0
5. First Flight Unit Fabrication Cost	<u>2.5</u>
	10.2%

The cost of a working prototype thus approximately equals 10.2% of the total flight hardware cost. Adjustments should be made, however, to reflect the effect of the number of flight units included in the total program cost. Table XII gives the estimated cost of high fidelity, but not flight qualified water recovery systems, based on the percentage cost values given above. The cost of prototype units may be lowered further depending on the degree of fidelity, packaging and/or miniaturization desired.

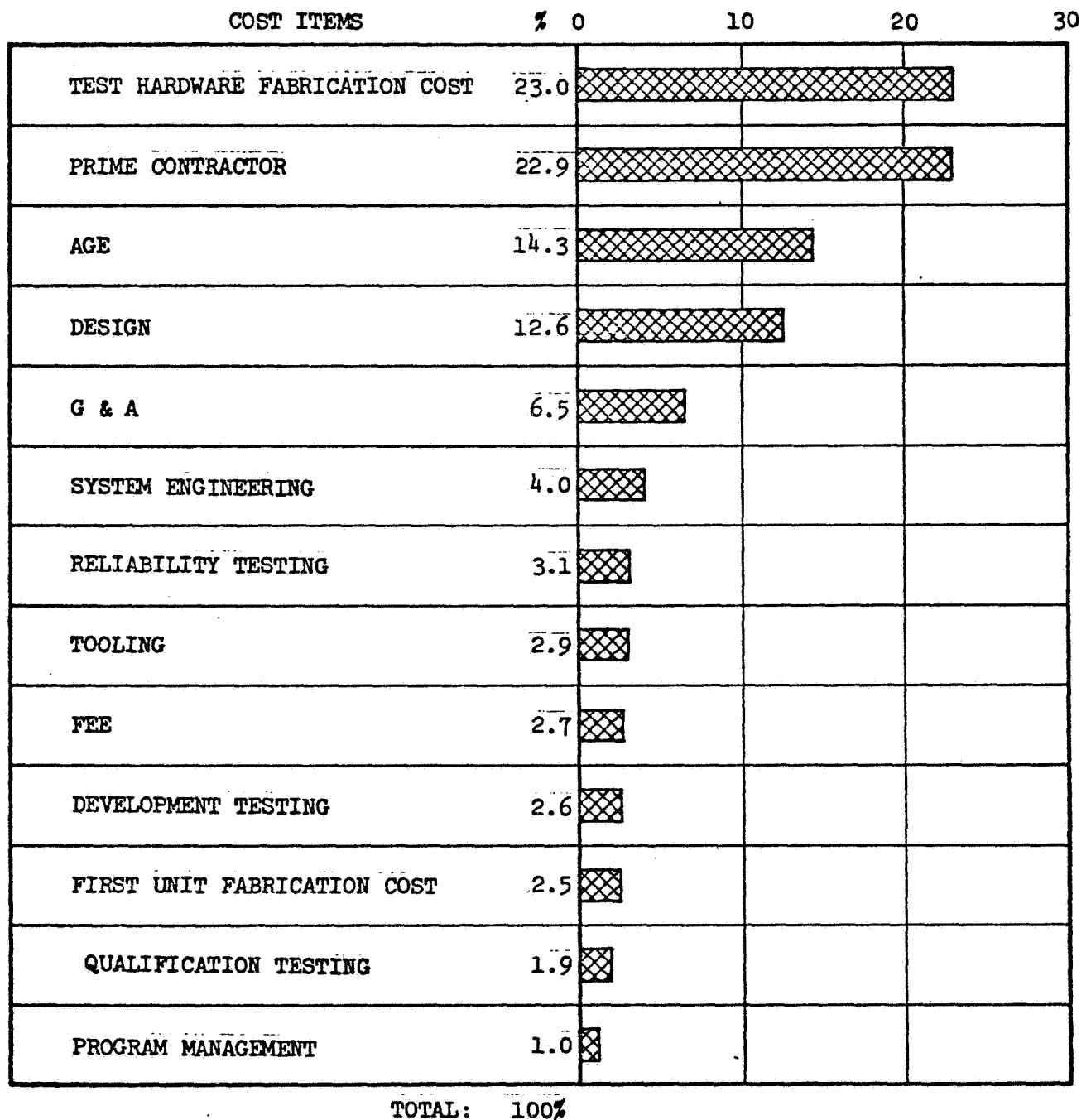







Figure 8 REPRESENTATIVE LIFE SUPPORT SYSTEM EXPENDITURE BREAKDOWN
(FIRST FLIGHT UNIT DEVELOPMENT COST)

COST ITEMS	%	0	10	20	30
TEST HARDWARE FABRICATION COST	0				
PRIME CONTRACTOR	0				
AGE	0				
DESIGN	12.6				
G&A	0				
SYSTEM ENGINEERING	4.0				
RELIABILITY TESTING	0				
TOOLING	0				
FEE	0				
DEVELOPMENT TESTING	2.6				
FIRST UNIT FABRICATION COST	2.5				
QUALIFICATION TESTING	0				
PROGRAM MANAGEMENT	1.0				

TOTAL: 22.7% OF QUALIFIED UNIT COST

Figure 9 REPRESENTATIVE LIFE SUPPORT SYSTEM EXPENDITURE BREAKDOWN
(OPERATIONAL PROTOTYPE DEVELOPMENT COST)

TABLE XII - PROTOTYPE COST ESTIMATES

COST ITEM	RITE SYSTEM	REVERSE OSMOSIS SYSTEM	MULTI- FILTRATION SYSTEM	VAPOR COMPRESSION SYSTEM	AIR EVAPORA- TION/ELECTRO- LYTIC SYSTEM
Engineering	511,985	308,901	233,475	394,450	435,067
Program Manage- ment	42,665	25,742	19,456	32,871	36,256
System Engineering	159,995	96,532	72,961	123,266	135,958
Development Test- ing	106,664	64,354	48,641	82,177	90,639
First Flight Unit Fabrication Cost	266,659	160,886	121,602	205,443	226,597
Prototype Cost	1,087,968	656,415	496,135	838,207	924,517